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THE

ORTHOPEDIC TREATMENT

OF

GUNSHOT INJURIES

BY

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WITH AN INTRODUCTION BY

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To All

WHO BY WORD AND DEED ARE

STRIVING TO AID THE

CAUSE OF THE

Crippled Soldier

THIS

BOOK IS DEDICATED

INTRODUCTION

IT is a satisfaction to give a welcome to a book that comes to us at a time when it is definitely needed. We are having to decide problems in surgery, which are either new, or which present such new phases, that we must re-adjust ourselves in the methods of their reception and treatment. Dr. Mayer, in his presentation of the subject in this book, has led to these important questions, and has given the results of a practical experience with many of the new problems which have come to us in the last three years of military life. It has been definitely demonstrated that early radical methods are frequently necessary for ultimate conservative results, and for the final completion of full function, and that continued treatment given as early as possible, and in many instances that the early application of correct mechanical principles, are necessary, if we are to have in mind the complete rehabilitation of the injured man. The importance of the restoration of the disabled individual back into his working life is now having its proper recognition, under the stimulus of war conditions, although we must remember that this problem is not new, for it has had, for some time, the attention of a few men, who had recognized its importance and have done much toward establishing this feature in industrial surgery. The need of surgeons who have a knowledge of these correct principles and of the mechanical supplements to surgery, is emphasized in this work of Dr. Mayer.

Dr. Mayer has called attention to the need of planning the treatment of long surgical cases so that the patient can be restored finally to his full function, and has also emphasized that this includes not only the restoration of his physical and mental condition, but also the restoration of the individual himself back to the position which places him in a wage-earning status. This is particularly applicable at the present

time, when so much is being planned for the complete re-habilitation of the men disabled in the war, and it is also valuable just now, to have this emphasized in the surgical task, the scope of which combines these two principles, directed toward the relief of the immediate (medical) and the remote (functional) conditions. It is wise to emphasize the relation of the application of the correct mechanical principles to surgical measures, to provide the ultimate as well as the immediate result, and to thus avoid the long and unnecessary after-treatment, in overcoming secondary defects and deformities, which may so frequently be avoided. The restoration of the injured man should begin with the first treatment, so that the plan should have for its object the uninterrupted care, from the first medical or surgical treat-ment, to the working period of the individual.

This attention to the mechanical features of treatment includes in many cases the fitting of artificial limbs. Too little thought and time has been given in the past by the medical profession to this most important subject, not only to the proper selection of the substitutes, but also to the fitting and training in their use, and to the early preparation of the stump for their reception. As much time and personal atten-tion should be given by the surgeon to this important subject as to that of splints and apparatus for acute joint affections. This subject is now beginning to have the proper realization of its importance by the prominence of its demands, and the reader will find in this book the proper emphasis on this phase of the work.

E. G. Brackett, Col. M. C., N. A.

PREFACE

This book is not a treatise on orthopedic surgery. Its purpose is merely to emphasize certain principles and rules of guidance in the treatment of war injuries that have been of value to me. These principles may be termed orthopedic since they deal with the prevention and cure of deformity. It is foolish to haggle over the definition of orthopedic surgery or to try to define the limits between it and general surgery. Every military surgeon who is called upon to work in a war hospital, must have orthopedic knowledge, and every orthopedist who has to treat gun-shot injuries must be a man of surgical attainments. The two specialties merge so intimately in all injuries of the extremities that the attempt to divorce them seems to me artificial.

In this work I shall not refer to those injuries or deformities, such as sprains or dislocations, that are commonly seen in times of peace, although a knowledge of their treatment is most important for the military surgeon, but only to those produced by the explosives of modern warfare. For the treatment of the former, the reader is referred to the classic text-books and to two publications of Sir Robert Jones, "Injuries to the Joints," and "Notes on Orthopedic Surgery." These two booklets are invaluable to everyone practising traumatic surgery.

I am considering the treatment of war injuries under two main groups: that given at the front, and that at the base hospital. In the field, the essential orthopedic problem is proper fixation of the injured part; in the base hospital, the proper time to discontinue fixation and restore motion.

The chapters on the injuries to tendons and the peripheral

nerves represent in condensed form the substance of a course given to military surgeons in Major Fred. H. Albee's Department of the Post-Graduate Hospital, New York City. I am led to include the anatomic data at the request of my students who have felt it of advantage to study the anatomic essentials stripped of the unnecessary encumbrances of the anatomic text-book.

One chapter of the book is devoted to artificial limbs, not that the subject is yet ripe for thorough treatment but because I hope thereby to interest medical men generally in this most important branch of study. Too often the surgeon merely amputates and leaves all else to the brace maker. This is an incorrect practice. Even the best brace maker is, after all a technician, not a physician, and the fitting of a prosthesis does not correspond to the fitting of a suit, but to the finest adjustment of an orthopedic brace or flat-foot support. Innate mechanical sense and an accurate knowledge of the anatomy and physiology of the locomotor apparatus are essential factors in the proper selection and application of an artificial limb. It is a task requiring all the skill that the physician can bring to his work, and frequently the problem is so difficult that it will baffle the best of us.

I am also including a chapter on the organization of reconstruction hospitals, since in the event of the continuance of the war this topic will demand earnest consideration by the American physician and social worker. In all the belligerant countries the reconstruction hospital has been recognized as essential to the welfare of the individual cripple and to that of the community, since it is the best method of rejuvenating the physically handicapped and of rendering them productive members of society.

The illustrations, except when specific mention is made of other sources, are from photographs and drawings made for or by me during my service as Orthopedic Surgeon to the Urban Red Cross Hospital and to the Oscar-Helene Home for Crippled Children.

To all who have assisted me in the preparation of this work,—to Mr. Martin Nordegg, to Dr. Thalhimer for revision of the proof and for preparation of the index, to Dr. Groeschel for service as photographer, to Major Fred H. Albee for friendly advice and above all to my publishers, W. B. Saunders Co., who have encouraged me by their warm interest and the accuracy with which they have carried out technical details, I wish to express my thanks and appreciation.

LEO MAYER.

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  NEW YORK CITY,
    June, 1918.

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ORTHOPEDIC TREATMENT OF GUNSHOT INJURIES

PART I

AT THE FRONT

Here two principles predominate in the treatment of all gunshot wounds of the extremities: surgical cleanliness and adequate fixation. It is with the latter that we are concerned.

CHAPTER I

FRACTURES AND INJURIES TO JOINTS

The method of fixation must comply with the following requirements:

1. It must prevent shortening and hold the fragments properly aligned.

2. It must be adapted to the transfer of the patient from the front to the base hospital.

3. It must allow free access to the wound not only for dressing but for incision in case of abscess formation.

4. The materials used must be such as to allow their ready transport.

It is self-evident that no one splint can meet the requirements of the many types of fractures and also that in many instances a variety of methods can be employed with equal effectiveness. In all cases, however, it is essential that the surgeon have sufficient mechanical skill to appreciate the

nature of the problem confronting him, and sufficient inge-
nuity to adapt the method to meet the demands of the indi-
vidual patient.

Splints are distinctly more advantageous than plaster-of-
Paris dressings, because the application of the latter demands
more time and also more experience on the part of the surgeon.
Since, however, the splints are not always to be had, whereas

Fig. 1.—The Leyva splint for the abduction treatment of fractures of the
upper end of the humerus.   Traction is secured by the adhesive straps fast-
ened to a hook attached to the end of the splint.

plaster-of-Paris is almost always obtainable, every surgeon
should be able to use it effectively.   It is a mistaken notion
that all the work at the front must be done in a hurry; this
happens only after extensive engagements when there is a
sudden inpouring of wounded.   In the usual type of trench
warfare, there is excellent opportunity for careful work and
accurate adjustment of the dressings.

**Fractures in the Neighborhood of the Shoulder, either of
the Humerus or of the Scapula.**—In the majority of cases, the
abducted position of the arm (50°) is indicated for three

reasons: First, because in the event of ankylosis of the shoulder the abducted position gives the patient 90° free play through the action of the scapula; second, because the fragments are usually best reduced by this position; third, because it relaxes the most important muscles of the shoulder, thus lessening the tendency to overriding and preventing unnecessary strain of the muscle fibres. There are, however, cases of fracture of the humerus in which the bony fragments are best aligned by less abduction, or even by bandaging the arm at the side of the body.
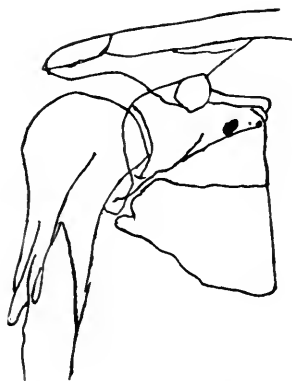

Fig. 2.—Severe comminuted fracture of the scapula and of the humerus. The line of fracture extends into the glenoid fossa. Treatment by the abduction method.

Abduction must not be accompanied by internal rotation of the arm, as in the case of the Mitteldorf triangle, but the arm must be kept in the neutral position—that is, one corresponding to its position when hanging at the side of the body with the thumb against the seam of the trousers. As the lower arm when fully extended would be too great a drag on any ambulant splint, it is bent at a right angle and therefore points forward in the same direction as the patient's toes (see Fig. 1). The upper arm lies slightly anterior to the mid-coronal plane of the body, since this position enables the patient to bring the hand to the mouth even if the shoulder is completely ankylosed.

Methods of Securing this Position.—The surgeon must have several at his command. If he is fortunate enough to be equipped with the abduction splint shown in Fig. 1 he need only apply this. The little splint of Sir Robert Jones (see

Fig. 3.— Photograph of the patient whose roentgenogram is given in Fig. 2 four months after the injury. Primary immobilization in the abducted position was followed by exercise treatment which resulted in almost the normal range of motion.

"Notes on Military Orthopedics," p. 123), though useful in paralytic cases, does not, I find, give sufficient fixation for fractures. An effective splint can be improvised rapidly in the following way:

Bend a wire splint or bar of malleable iron to form a triangle whose one leg corresponds in length to the patient's body from the axilla to the crest of the ilium; whose second leg measures from the axilla to the elbow; the third leg reaches from the elbow to the iliac crest. To the angle supporting the elbow, a second splint is attached by a rivet or a

Fig. 4.—The fenestrated abduction plaster dressing for injuries in the neighborhood of the shoulder and fractures of the upper portion of the humerus. Extension is secured by means of the adhesive straps and a strong piece of rubber tubing attached to the hook-like prolongation of the splint beyond the elbow.

few turns of wire, so as to support the forearm which has been bent at right angles to the upper arm. This frame is then heavily padded with sheet wadding and fastened to the patient's side by plaster-of-Paris bandages, passing around the torso and over both shoulders. In case traction is necessary because of overriding, the splint is easily modified by prolonging the second leg of the triangle (corresponding to the upper arm) several inches further for the attachment of adhesive strips fastened to the arm (see Fig. 4).

In all plaster-of-Paris dressings for compound fractures, provision must be made to prevent soiling by the wound secretions. A primary essential is to have the window sufficiently large to expose at least two inches of healthy skin on all sides of the wound. Further protection of the plaster is given either by cuffs of oiled skin (Osgood) or by strips of cotton

FIG. 5.—Jones' modification of the Thomas arm splint for use in fractures of the humerus and injuries to the elbow.

soaked in paraffin, so placed as to close in the slight gap between plaster and skin and to cover the free ends of the plaster.

Fractures of the Shaft of the Humerus.—These must be considered in two groups; those above the insertion of the deltoid, and those below this point. In those above, owing to the pull of the powerful abductor, the lower fragment must be abducted to secure the proper alignment; in those below

FIG. 6.—A plaster fenestrated dressing applicable to gunshot injuries of the lower end of the humerus and of the elbow. Traction is exerted either by adhesive strips fastened to the upper arm or in case the wound prevents their application, by a bandage running over the forearm, just below the bend of the elbow.
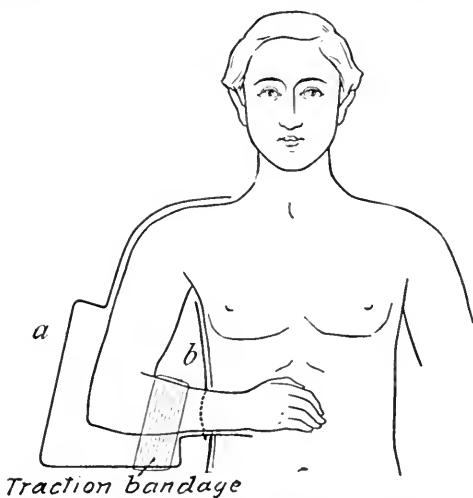

FIG. 7.—Diagram illustrating the iron bands incorporated into the plaster dressing shown in Fig. 6. *a*, The outer iron band. *b*, The inner band which runs along the patient's chest and partly encircles the arm.

the insertion of the deltoid, abduction is usually not necessary. For the first type, the abduction splints already described are applicable; for the second (those of the lower half of the shaft), the modified Thomas elbow splint is well adapted (see Fig. 5). If this is not to be had, an excellent fixation is secured by the fenestrated plaster splint reinforced by iron bands, as shown in Fig. 6. The technic of application is as follows:

Fig. 8.—The wrenches used to bend the iron bands in applying a fenestrated plaster dressing.

Two malleable iron bands are necessary, $1\frac{1}{8}$ inches thick, about $1\frac{1}{2}$ inches wide and 1 yard long. The surgeon should provide himself with a small vise, triangle file and hammer, so as to cut off the band at the point desired. The first is bent corresponding in form to that marked A in Fig. 7; it follows the outline of the shoulder and the upper arm to a point several inches above the wound, then bends sharply at a right angle outward, then downward, then corresponding to the bend of the elbow, forward parallel to the lower arm, and then again at a right angle, so as to bring it once more against the surface of the patient's extremity. The

second band, corresponding to B in the figure, passes along the patient's
chest and is made to form a loop supporting the lower arm. A little prac-
tice readily gives the surgeon an adequate technic. A pair of irons, as
shown in Fig. 8, are of assistance in bending the metal. Each of the
iron bands is now wound with a gauze bandage so as to insure more
intimate union with the plaster-of-Paris. The patient's body and the
shoulder of the injured side are well padded with cotton wool, as is also
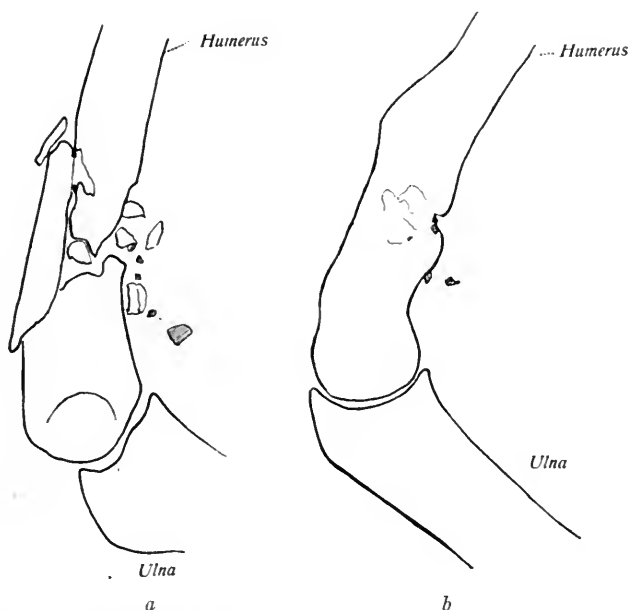

Fig. 9.—Tracing of roentgenograms of compound comminuted fracture of
the humerus just above the elbow joint, associated with extensive laceration
of the soft parts. *a*, One week after injury. *b*, Eight weeks later. Treat-
ment by the fenestrated plaster dressing shown in Fig. 6.

the forearm. The padding is bound firmly in place by gauze bandages
and then everything is ready for applying the plaster-of-Paris. Sufficient
turns are applied to give a layer approximately $\frac{1}{8}$ inch thick, and then
the two iron bands, which have already been bent, are laid in place and
fastened by further turns of the plaster-of-Paris bandages. Within a
few minutes the splint is hardened. To hold the arm in the desired
position a traction bandage is applied to the forearm just below the elbow
(see Fig. 7). The fixation is excellent, and at the same time allows
access to the most extensive type of wound. Figs. 9*a* and 9*b* are tracings

of roentgenograms of a gunshot injury just above the elbow at the time of application of the splint and after healing has occurred.   In Figs. 10a and 10b, the patient is seen, illustrating the range of flexion and extension secured by this method.

Injuries in the Neighborhood of the Elbow.—As in the case of the shoulder, the surgeon must always consider the danger of ankylosis and immobilize in the position most convenient

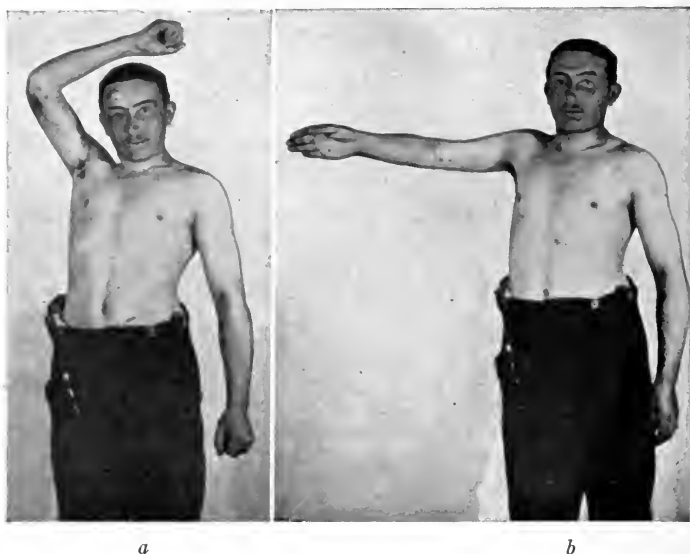a   b

Fig. 10.—Photographs of the patient whose roentgenograms are shown in Fig. 9, illustrating the range of flexion and extension three months after injury.   The primary immobilization was followed by treatment with the Schede splint, by means of which almost the normal motion was secured.

to the patient were ankylosis to occur.   This is one of flexion of about 70° with the forearm midway between pro- and supination, that is, with the thumb pointing up, the little finger toward the ground.   The splints already described for fracture of the lower end of the shaft of the humerus are also applicable to these fractures and joint injuries.

The Bones of the Lower Arm.—The problem is much more difficult when both bones have been fractured than

when one is still intact to act as a splint for the other. In the latter case (that is, when only one bone is fractured) many methods can be applied with equally good results. The surgeon must merely appreciate the pathological condition involved. As a rule, the fragments of the fractured
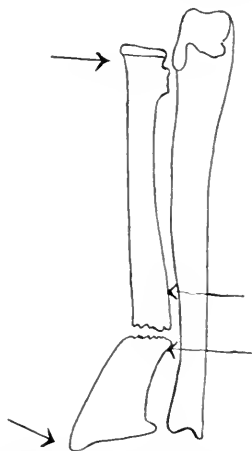

FIG. 11.—Diagram illustrating the type of deformity frequently seen in gunshot injuries to a single bone of the forearm. The arrows indicate the lines of force which the surgeon should apply in reducing the fracture. The object of the reduction is the prevention of a bridge of callus between bones, which would prevent pro- and supination.

bone bend in toward the non-injured bone in such a way as to form a distinct angle. The danger in these cases is that a bridge of callus will form between the two bones of the lower arm, thus preventing pro- and supination. The object of the splint is to apply pressure in such a way as to force the extremities of the fragments outward. This can be accomplished: (1) by a fenestrated plaster splint; (2) by a moulded plaster splint; (3) by metal splints; (4) by padded wooden splints. They should hold the arm supinated, since in this position there is least danger of union between the ulna and radius.

The fenestrated plaster is applied by first padding the arm suitably and holding the padding firmly in place with a gauze bandage. The wounds can be marked either by indicating the corresponding positions

on the patient's sound arm or, better still, by inserting two little wooden markers. These are discs of wood about 2 inches in diameter with a straight rod 2 or 3 inches long projecting from their centre. The plaster-of-Paris is then applied, covering the lower arm and the lower half of the upper arm. As the plaster is hardening, the surgeon grasps the fractured bone above and below the site of the lesion, exerting force in the direction of the arrows as shown in Fig. 11. This tends, in the great majority of cases, to lever the fragments from the intact bone. The wounds are exposed for dressing by cutting windows in the plaster at the points designated.

Fig. 12.—Fenestrated plaster dressing applicable to severe gunshot injuries of both bones of the forearm.

The moulded splint is prepared by folding a plaster-of-Paris bandage backward and forward on a table until sufficient thickness has been secured to form a firm dressing. This is then applied to the side of the arm and held in place with several turns of gauze bandage. While it is hardening, the surgeon corrects the position of the bones as in applying the fenestrated plaster.

The application of the metal splints and of the padded wooden splints is made according to the same principles.

If both bones are broken, I know of no splint which gives perfect functional results in the very severe cases. A good method is the fenestrated plaster dressing reinforced by iron

bands, as shown in Fig. 12.   The technic of application is
much the same as in the case of fractures near the elbow.

A single iron band is used, bent as indicated in the photograph.   The
arm is padded above and below the site of the lesion.   Plaster-of-Paris is
first applied over the padding, then the iron band is inserted and held
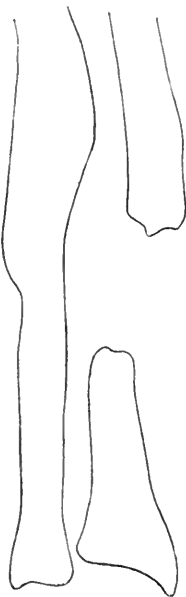

Fig. 13.   Fig. 14.

Fig. 13.—Tracing of roentgenogram of severe shell injury to both bones
of the forearm, ten days subsequent to injury.   Treatment by means of
the fenestrated plaster shown in Fig. 12, which permitted the five incisions
necessary for adequate drainage of the wound.

Fig. 14.—Three months later.   The gap between the two ends of the
radius was bridged later by a bone graft.

in place with a final series of plaster turns.   Care must be taken to give
the fingers plenty of room so that as soon as the muscles have recovered
from the effect of the extensive traumatism they will be given fair chance
to functionate.   In Figs. 13 and 14 are shown tracings of roentgeno-
grams of such an injury at the time the splint was applied, and twelve
weeks later.   The gap between the fragments of the radius was subse-
quently bridged by a bone graft.

The modified Thomas humerus splint, when supplemented by a traction bandage above the elbow and adhesive straps to the lower arm, pulling the wrist forward can also be applied in fractures of this type.

Injuries at the Wrist.—In these cases it is essential to fix in hyperextension so as to preserve the strength of the grip in case of ankylosis.   The position is easily secured by a moulded plaster-of-Paris splint or by the hand splint of Sir Robert Jones.   In case the injury happens to be on the anterior surface of the arm, the splinting method must be modified by using lateral braces instead of anterior ones.

Injuries to the Hand.—One or more of the metacarpal bones are usually hopelessly shattered and the tendons injured.   Methods of traction are of little avail in these cases and there is practically nothing to be done at the front except to fix the hand in a position of moderate extension by one of the methods outlined for injuries to the wrist.   Whether the splint be of wood, plaster-of-Paris, or metal, it should always be so adjusted as to leave the wound free for the dressing or for irrigation methods.

Injuries to the Fingers.—These offer great opportunity for the surgeon's ingenuity, since fingers which seem hopelessly damaged can, by the appropriate treatment, be rendered useful members.   The best splint is either a rounded bit of metal corresponding in length to the finger or a wooden tongue depressor.   These are applied to the finger by adhesive strips in such a way as to correct the deformity by traction, pressure or torsion.   In Fig. 15 I have indicated how in case of lateral angulation the adhesive bands are applied so as to overcome the deformity of the fractured phalanx.

Injuries to the Spine.—These require rigid fixation not only of the vertebral column but also of the head and thigh.   The Jones splint and the Bradford frame, both commonly used in the treatment of Pott's disease, are excellent for the purpose. If they cannot be had, a plaster-of-Paris bed which meets the requirements can be made rapidly and cheaply in the following way:

The necessary materials are (1) ten 8-inch plaster bandages; (2) eighty strips of common burlap, such as is used for making bags, each

strip about 8 inches wide by half a yard long; (3) a pail of plaster-of-
Paris. The patient is placed, face downward, on a narrow table. The
back and thighs are greased with a little oil or petrolatum, and a piece
of stockinette is laid over the head, to keep the plaster from the hair.
One assistant is necessary to help apply the bandages; a second assistant
to mix the plaster-of-Paris and pass the bandages. The work is begun
by the second assistant, who begins mixing a plaster cream. This is
done by shaking the plaster-of-Paris slowly into half a pail of cold water,
and stirring gently until the correct consistency has been reached.
Meanwhile the operator and the first assistant apply the plaster-of-Paris
gauze bandages from the thigh to the head in a series of overlapping
turns which entirely cover the patient's back. A single layer suffices.

Fig. 15.—Photograph illustrating the method of overcoming lateral deviation
of the fingers, subsequent to gunshot injuries.

When the plaster cream is ready, the burlap strips are dipped into it
one by one, and when thoroughly saturated with the plaster are handed
to the operator who applies a series of strips first in the vertical direction,
then in the transverse direction; and a final series in the vertical. At
the neck, an extra series of strips should be applied because the tendency
to break is greater at this point than at any other; it is even a wise plan
to strengthen this portion of the bandage by two small pieces of malleable
iron, bent at the appropriate angle. When the burlap strips are all in
place, the remaining plaster cream is poured over the patient and rubbed
into the burlap. The splint is completed by a series of plaster bandages
corresponding to the layer first applied to the skin. Usually, the plaster
has hardened a few minutes after its application, and with a little care

it can be removed from the patient's body, the edges trimmed, with a strong knife, and a suitable opening cut over the wound. Near the anus the plaster is cut away, allowing ample room for defecation. It requires 20 to 30 minutes to make such a plaster bed. Despite the absence of padding, it will be found that if the technic has been accurate, the patient will be comfortable and that there is comparatively little tendency to decubitus formation. If possible, the splint should be allowed to dry for three days, before using it as a permanent dressing.

Injuries to the Hip.—In lesions to the hip, the position to be given the limb depends upon the pathological condition.   If the femoral head or the acetabulum has been extensively injured with consequent danger of ankylosis, it is best to abduct about 10°, and flex about 5.   This is the position which most patients find of greatest advantage in case ankylosis occurs. If, however, the danger of infection seems comparatively slight, and the bullet has produced a simple fracture of the neck, corresponding to that seen in the ordinary traumatic cases, then the position of marked abduction, as advocated by Bardenheuer and by Whitman, is to be preferred. Of course, it is not easy for the surgeon at the front without aid of the x-ray, to differentiate between these two conditions; yet by careful palpation and inspection of the wound enough can be learned in many instances to enable him to apply the method of choice.

There are at least two good methods of fixing the hip.   In both, the essential factor of the fixation is a firm grasp, not merely of the lower extremity, but also of the trunk to the level of the nipples.   The Jones abduction splint (Fig. 16) and the plaster-of-Paris spica are the two best means.   In applying the plaster-of-Paris, the patient's buttocks and shoulders must rest on some support, and the legs must be held in the line of the body, either by assistants or by an appropriate suspension apparatus. In case a hip rest is not at hand, one can readily be improvised by nailing two discs of wood, each about 4 inches in diameter, to a 6-inch length of broom-stick.   The upper disc is padded with felt or cotton wool. In applying the plaster, no peculiar technic is necessary except in those instances where the wound is very extensive. Then it is impossible to give access to the wound without endangering the solidity of the splint. In these cases,

it is necessary to reinforce the plaster by strong bands of malleable iron, so bent that they bridge the area of the wound, leaving ample space between them and the skin for the surgeon's instruments. They are applied in the same way as the fenestrated splints already described for the arm (p. 24).

In the treatment of injuries to the hip, as well as in all other cases of injuries to the leg, it is always necessary to prevent
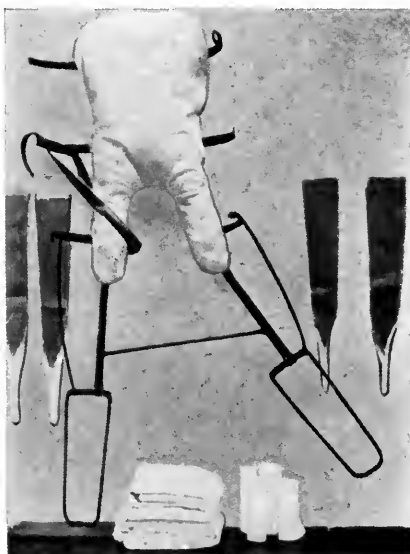

Fig. 16.—Abduction frame.   (*Jones.*)

drop-foot. It is therefore well to prolong the spica to the toes, cutting out on the dorsum of the foot so as to give the patient the maximum amount of freedom.

Fractures of the Upper Third of the Femur.—In these, the common deformity is due to an abduction of the upper fragment, and an adduction of the lower, producing an angulation, as shown in Fig. 17. In my own experience in the base hospital, I found that practically all of the fractures in this portion of the femur, despite the fixation at the front, showed

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this typical lack of alignment. In all of them this was due to insufficient traction and to the lack of a proper counter-traction. Far and away the most efficient method of treating these fractures is by means of the Thomas knee-splint. The pelvic ring furnishes excellent counter-traction, and ample traction can usually be secured by means of adhesive plaster bands attached to the lower end of the splint. A modification

Fig. 17.—Fracture of upper third of the femur, produced by infantry bullet, showing the deformity typical of this type of fracture.

of the splint which allows of further traction by means of a simple ratchet and screw, adds to its effectiveness (see Fig. 18). In case the adhesive plaster does not hold, or if much shortening has already occurred, it is advisable to get a direct grip on the bone by some other method. Driving a nail through the condyle of the femur, as advocated by Codivilla and Steinmann, is an effective method but not entirely safe, owing to the danger of infection. I prefer what may be termed the "ice-tongs"

method. A strong pair of hooks (Fig. 19) resembling the ordinary ice-tongs, can, while the patient inhales a few whiffs of chloroform, be made to grasp the condyles of the femur, and when the handles of the tongs are approximated a traction of 40 or 50 pounds can be exercised without danger of slipping. Extreme asepsis must of course be practised, and not only the wound produced by the tips of the tongs, but the entire instrument, should be swathed in sterile gauze.

Fig. 18.—The modified Thomas knee splint. This model differs from the original in the attachment of a foot piece preventing the drop-foot and in the addition of a ratchet and screw, facilitating the method of applying traction.

If the Thomas splint is not procurable, recourse must be had to plaster. I know of no splint that is more difficult to apply correctly than this. The great difficulty lies in the proper construction of the counter-traction against the patient's pelvis. The patient is placed on a hip rest, the shoulders and legs are supported as already outlined, and the parts are appropriately padded. A strip of felt, about 3 inches wide by 8 inches long, is held firmly against the spine of the ischium and the ascending ramus by means of a piece of cotton flannel 2 yards long and 3 inches wide, the ends of which are grasped by an assistant and pulled taut in the direction of the patient's head. When applying the plaster, particular care must be taken to mould it firmly against this piece of felt, since otherwise the close fit required for effective counter-traction is not furnished. Some means of traction must now be devised. That which consists in applying strips of adhesive to the leg and then turning these adhesive strips backward over the plaster so as to incorporate them in the bandage, has never proven effectual in my hands, nor have I seen good results even from the men who most enthusiastically advocate its use. The adhesive tends to give, and within a few days all semblance of effectual traction has been lost. Whatever traction method is adopted,

it must be such that the slack can be taken up from day to day.   An
excellent method is the incorporation of a stout iron band into the lower
end of the plaster, which forms a projecting loop some 6 or 8 inches below
the level of the sole (see Fig. 20) serving for the attachment of the ad-
hesive plaster strips.   Of course, when this method is adopted, the foot
is not to be included in the plaster bandage.

Fig. 19.—The bone-tongs for the direct method of applying traction.   The
sharp prongs penetrate the cortex easily and are held in place by the traction
of the cord which passes through the handles.

In the severe cases with extensive overriding of the frag-
ments, sufficient traction by means of the adhesive plaster may
be impossible.   Then the bone-tongs should be used or a
stout piece of wire can be passed directly through the os calcis
by means of the ordinary bone-borer, and direct traction
applied to the bones by this means.

In some instances it is impossible to secure alignment of the ends of the bone by these methods, owing to the marked abduction of the upper fragment. Then the lower fragment must also be abducted until the corresponding angle is reached, and fixed in this position, either by the Jones abduction splint or by

Fig. 20.—Fenestrated plaster dressing with stirrup extension enabling the patient to walk without bringing his weight upon the fractured limb. The plaster must be carefully moulded about the tuberosity of the ischium, which is protected by a suitable pad of felt. A similar splint can be applied to a patient in the recumbent position; then the stirrup extension serves for the attachment of the adhesive straps which exert traction upon the fractured limb.

the plaster abduction spica. Traction is necessary in this position as well as in the non-abducted to prevent shortening.

Injuries in the Middle Third of the Femur.—In these there is no deformity that can be spoken of as typical. In many cases the fragments have interlocked in such a way as to prevent shortening, and the surgeon need merely apply two lateral

moulded splints or two of the rounded metal splints used by
Jones to hold the fragments properly aligned.   In other
instances, there may be very marked overriding with devia-
tion of the lower fragment, usually to the inner side or with
backward angulation.   When this occurs, the traction methods

FIG. 21.—Compound fracture of both femurs due to gunshot injuries of both
the thighs three months after treatment in a double fenestrated plaster spica.

outlined for fracture of the upper one-third must again be
applied.

Injuries to the Lower Third of the Femur.—As a rule, the
lower fragment is displaced backward by the powerful pull of
the gastrocnemius.   The Thomas splint is a most effective

agent in overcoming this backward displacement. Sir Robert
Jones relates in one of his essays how in a case of this kind his
house surgeon who had adopted an exceedingly skeptical
attitude toward his "Attending's" methods of treatment, pre-
pared all his instruments ready to ligate the popliteal artery
because he was sure the fragment would penetrate the vessel
if no other traction were employed than that given by the
Thomas splint. The house surgeon was much surprised when
he found his preparations unnecessary, since within 2 days
after the injury a perfect alignment had occurred.

The plaster-of-Paris method is also applicable although
more difficult in technic and much more time-consuming.

Injuries to the Knee.—Rigid immobilization is particularly
essential in these cases to prevent spread of an infectious pro-
cess. Although some authors favor a position of flexion to
about 30°, maintaining that this position is more convenient
to the patient in case of ankylosis, I have found it more ad-
vantageous not to flex the leg more than 5°, since even if
ankylosis does occur, the patient prefers a good walking leg,
even if this be in the way when sitting, to one good neither for
walking nor for sitting. The latter I find to be the case when
the knee is ankylosed at 30° of flexion. The surgeon must
be particularly careful to avoid hyper-extension at the knee,
such as is almost certain to occur when a perfectly straight
splint is applied. To avoid this unsightly and crippling de-
formity, the leg should always be slightly flexed.

The methods of splinting are again (1) the plaster spica,
including the pelvis and the foot; (2) the Thomas splint. As
a last resort, if neither can be applied, the Volkmann leg splint
can be used. This consists of a metal trough extending from
the heel to the hip, with a right-angled foot piece to prevent
drop-foot. Its disadvantage lies in the fact that owing to its
failure to include the pelvis, the fixation is not secure.

Injuries to the Bones of the Calf.—Fractures of the fibula
alone are exceedingly simple to splint, since the tibia holds the
fragments in place. Frequently fractures of the tibia alone
are splinted by the action of the uninjured fibula. In both
these events, an effective external splint is readily made either
by two moulded plasters or by two lateral metal splints. The

Volkmann splint may also be used. If, however, both bones have been broken and there is overriding of the fragments, extension must be applied. When the injury lies in the upper half of the calf, adhesive plaster strapping attached to the Thomas splint or to the iron bar incorporated in a plaster dressing extending to the pelvis, gives effective extension. In
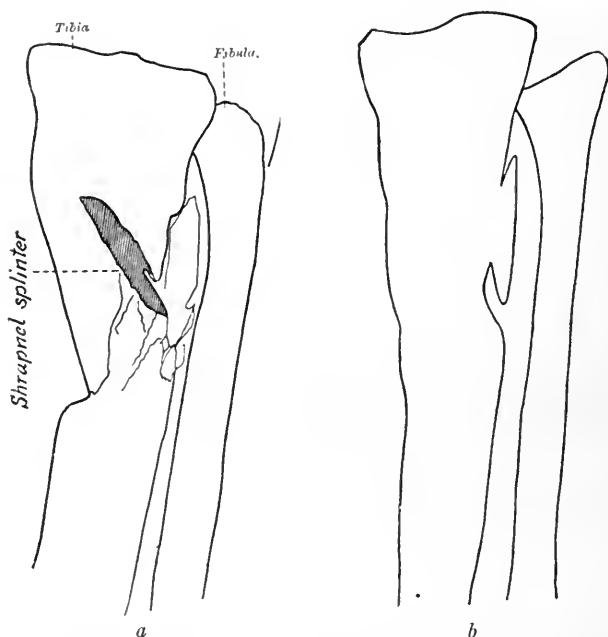

FIG. 22.—Tracing of roentgenogram of the patient illustrated in Fig. 23. *a*, One week after the injury. *b*, Three and a half months later.

those instances, however, where the fracture lies near the ankle-joint, it is impossible to secure the necessary traction by adhesive plaster and then recourse must be had either to a nail driven through the lower extremity of the tibia, to the bone-tongs, or to the wire method referred to on page 36. The surgeon must not rest content until he has applied sufficient traction to overcome the shortening. The danger of infection which may be urged as an argument against the insertion of

any instrument directly into the bone, becomes minimal if careful asepsis be exercised.

If there are extensive wounds of the soft parts, as was the case in the patient whose roentgenogram-tracing is shown in Fig. 22, the fenestrated plaster dressing reinforced by iron bands can be used to great advantage. To prevent sagging of the calf backward, it is held by a gauze bandage (see Fig. 23) in which it rests comfortably as in a hammock.

Fig. 23.—A fenestrated plaster dressing for severe compound fracture of the tibia. The backward sagging of the bone is prevented by the gauze bandages in which the leg is suspended as in a hammock. For the roentgeno-gram of this case see Fig. 22.

Injuries to the Ankle.—When wounds are present on both the internal and external aspects of the joint, with a drainage opening on the posterior surface, these are, in my experience, the most difficult of all gunshot injuries of the bones to splint properly. Even the ingenious crab splint of Jones fails to meet the requirements of these extensive lacerations. The only method I have found of avail is the fenestrated plaster dressing reinforced by iron bands, as shown in Fig. 24. The padding and plaster are applied as described on page 25, then the iron band, bent as indicated in the figure, is fastened in place by another layer of plaster bandages. The loop of metal projecting beyond the toes serves for the attachment of the adhesive plaster strips which keep the foot from slipping backward.

The problem is as easy in the cases where there is a clean wound as it is difficult in the extensive lacerations. Any one of several methods may be employed to hold the foot at right angles and fix it in this position: the crab splint, the Volkmann, the moulded plaster, or the wooden splint—consisting of two boards nailed together at right angles and suitably padded.
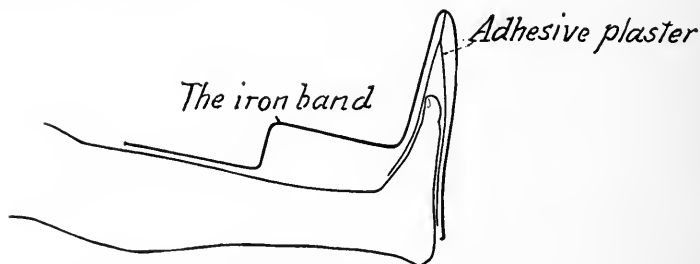

Adhesive plaster

The iron band

Fig. 24.—Diagram illustrating the dressing applicable to severe injuries to the ankle joint which require free incisions not only laterally but posteriorly. The iron band is incorporated in a plaster dressing which encircles the upper two-thirds of the calf and the metacarpal region of the foot. The adhesive plaster prevents a backward sagging of the foot.

Injuries to the Metatarsal Bones and to the Toes.—Little can be accomplished by a splint, since, except in very extensive injuries which usually demand amputation, it seldom occurs that more than one or two bones are shattered, and those not injured act as effective internal splints. Drop foot is prevented and the patient rendered more comfortable by a well padded external support which holds the foot at a right angle to the leg.

CHAPTER II

INJURIES TO THE NERVES

Lesions of the peripheral nerves complicate so large a per-
centage of gunshot injuries to the extremities that no exami-
nation of a wounded soldier is complete unless the surgeon
tests the function of the nerves that may have been injured.
This neurological examination is important even at the
front, since the treatment of the nerve injury should begin as
soon as the patient reaches medical hands. A splint for the
nerve is frequently fully as important as a splint for the
fractured bone, and just as the bone injury must be treated
at the front, so, too, the nerve injury should be properly
cared for without delay. It is therefore necessary for every
surgeon to have at his fingers' ends the simple tests for nerve
injuries. I am led to give these in detail, because experience
in approximately 100 cases of gunshot injuries of the peripheral
nerves has shown that the classical descriptions are in some
instances inaccurate.

Symptoms of Injury to the Peripheral Nerves.—1. *Musculo-
spiral Nerve.*—The patient is unable to extend the hand at the
wrist, to extend the proximal phalanx of the four fingers, or
to extend the thumb. Extension of the two distal phalanges
is possible owing to the action of the interossei and lumbricales
which insert into the extensor tendon just proximal to the
first interphalangeal joint. Supination is weakened and,
in cases of injuries to the musculospiral near the axilla, ex-
tension of the elbow is also weakened. Total paralysis of
the triceps occurs only as the greatest rarity, because that
branch to the inner head known as the ulnar collateral pur-
sues a separate course and is therefore not encountered by
the projectile which has injured the parent trunk.

The sensory disturbance varies markedly from case to case.
In not one instance did I see an anæsthesia corresponding to

the distribution of the sensory branches of the nerve, that is, over the dorsum of the thumb, second, third, and half of the fourth finger. Usually the anæsthetic area is not larger than a fifty-cent piece, and is located on the dorsum of the hand near the base of the thumb. Very often, however, even the most careful tests fail to reveal any sensory disturbance whatever.

2. *Ulnar Nerve.*—Injuries to this nerve are peculiarly variable in the extent of the motor symptoms. In some cases there is a very marked interference with the flexion of the fingers; in other instances, there is no appreciable disturbance except a slight weakening of the fourth and fifth fingers. The only

Fig. 25.—The contracture of the fourth and fifth fingers characteristic of paralysis of the ulnar nerve.

motor symptom that is constantly found is the inability to spread the fingers wide apart, due to the paralysis of the *dorsal* interossei. Even this symptom must be viewed critically since the long extensor tendons enable the patient to spread the fingers somewhat apart. In contrast to the variability of the motor symptoms, is the constancy of the sensory disturbance. There is regularly anæsthesia over the entire little finger, the ulnar half of the fourth finger, and the ulnar border of the hand. In cases where the injury to the nerve occurs a short distance above the wrist, the anæsthetic area is present only on the palmar surface, owing to the fact that

the dorsal sensory branch leaves the nerve some few inches above the annular ligament and is therefore spared by the projectile.

Immediately after the injury there is no tendency to deformity. Gradually, however, in the majority of the untreated cases a contraction of the fourth and fifth fingers occurs (see Fig. 25). This was so marked in a number of patients that when they were referred to me the nails of the affected fingers were cutting into the palm and the patients were clamoring for amputation. The flexion contracture of the fourth and fifth fingers is a paralytic phenomenon peculiar to the ulnar nerve. It may be due to scar tissue formation in the flexor muscles and their consequent shrinking, but this explanation, like others, is purely hypothetical. The later cases of ulnar paralysis are also characterized by the marked atrophy of the interossei and of the muscles of the thenar and hypothenar eminences. A ''main en griffe,'' as described by Duchenne, I have never seen, even in cases untreated for two and three years after the injury.

3. *Median Nerve.*—There is regularly a marked interference with the flexion of the fingers, particularly of the thumb, index, and middle fingers. Flexion of the wrist is possible owing to the action of the strong flexor carpi ulnaris. The sensory disturbance as a rule corresponds accurately to the distribution of the nerve and is found over the thumb, index, middle, and radial half of the ring fingers on the palmar surface. A portion of the palm on the radial half is also anæsthetic.

Although the pronating muscles are also paralyzed by a lesion to the nerve occurring above the elbow, great care must be exercised in testing for their function, since an agile patient can almost always by a clever use of the brachioradialis swing his arm from the supinated position into the pronated. To prevent this vicarious action of the brachioradialis (supinator longus), the patient's arm must be so twisted that the dorsum looks toward the ceiling, not with the thumb toward the inner side, but with the elbow so bent that the thumb points away from the body. In this position, pronation must overcome the weight of the arm, whereas in other positions, the weight of the arm assists in pronation.

4. *Musculocutaneous.*—There is a weakness of flexion of the elbow, but not a complete paralysis, owing to the presence of the non-paralyzed muscles which spring from the internal and external condyles of the humerus (pronator radii teres, flexor carpi radialis, brachioradialis, extensor carpi radialis longus and brevis). Sensory disturbances are usually not to be found owing to the overlapping by other nerves.

5. *Circumflex.*—There is a paralysis of the deltoid and of the teres minor. The latter is difficult to diagnose but paralysis of the deltoid prevents the full abduction of the arm. The action of the supraspinatus combined with that of the trapezius suffices to abduct the arm to 90°; for complete abduction, however, the deltoid is essential. The sensory disturbance is not constant.

For some peculiar reason, isolated injuries to this nerve are seldom seen in military surgery. Stewart and Evans, in their series of 316 cases, and Spitzy of Vienna, in 250 cases, report not a single instance of injury to the circumflex. Foerster of Breslau, reporting 1490 cases, of which 355 were injuries to the musculo-spiral states that lesions of the circumflex occurred in only an insignificant number.

6. *Brachial Plexus.*—Injuries are quite frequent, either from wounds above the clavicle or in the axilla. The arm hangs absolutely helpless by the side, there is complete anæsthesia of the hand, forearm, and usually of a portion of the upper arm. Depending upon the site of the injury, there may or may not be involvement of the pectoral muscles and of the serratus magnus. In case the latter is involved, the patient shows the characteristic winged-scapula deformity.

7. *Great Sciatic.*—Even in those cases where the injury occurs near the sacro-sciatic foramen, the flexors of the knee are not completely paralyzed, because in the first place a number of branches to the hamstrings are given off from the nerve immediately after it leaves the pelvis and in the second place the gracilis and sartorius, supplied by nerves of the lumbar plexus retain their normal function. The foot is completely paralyzed in all cases, and is anæsthetic except over a small area on the inner aspect supplied by the internal saphenous nerve.

When the injury occurs in the middle third of the thigh, there is no perceptible weakening of the hamstring muscles.

8. *External Popliteal.*—Dorsal movement of the foot (dorsal flexion) and eversion are impossible, owing to the paralysis of the tibialis anticus, extensor proprius hallucis, extensor longus digitorum, and the peronei. The anæsthetic area covers the entire dorsum of the foot and of the toes.

9. *Musculocutaneous (of the calf).*—Eversion of the foot is weakened but not inhibited, owing to the fact that the extensor longus digitorum and the peroneus tertius (both supplied by the anterior tibial nerve) also act as everters. The anæsthetic area covers the dorsum of the foot and the toes except the contiguous surfaces of the great and second toes.

10. *Anterior Tibial.*—Dorsal flexion of the foot is impossible. There is an anæsthetic area on the contiguous areas of the great and second toes, as indicated above.

11. *Internal Popliteal.*—The symptoms vary, depending upon the site of the injury. If this occurs above the point where the branches to the gastrocnemius leave the nerve (near the upper limit of the popliteal fossa) the plantar motion of the foot is impossible. If below this point, the foot can be brought into a position of equinus, but the motion is weakened and flexion of the toes is impossible. The anæsthetic area is the same in both instances and covers approximately the sole of the foot.

12. *Posterior Tibial.*—There is normal motion of the Achilles tendon, pulling the foot into the equinus position, but owing to the paralysis of the flexor longus hallucis and flexor longus digitorum the toes cannot be bent. Adduction is possible, despite the paralysis of the tibialis posticus, owing to the action of the tibialis anticus and of the Achilles tendon.

The diagram (Fig. 26) summarizes the terminal distribution of the motor branches of the sciatic nerve and enables the surgeon to diagnose the lesion almost at a glance.

13. *Rare Nerve Injuries.*—(*a*) *Intercostals.*—There is no appreciable sensory disturbance but electrical and mechanical stimulus of the muscles in question fail to cause a contraction.

(*b*) *Phrenic.*—Unilateral injury can be beautifully demon-

strated by x-ray pictures of the diaphragm which show a
diminished excursion on the injured side.

(c) *Cervical Sympathetic.*—The eye is slightly sunken on the
affected side, there is a slight ptosis which the patient, how-
ever, can voluntarily overcome, since the voluntary fibres of
the levator palpebri are not affected but only the involuntary
fibres supplied by the sympathetic. The pupil is slightly
smaller than the normal. There may be flushing or sweating
of the half of the face affected.
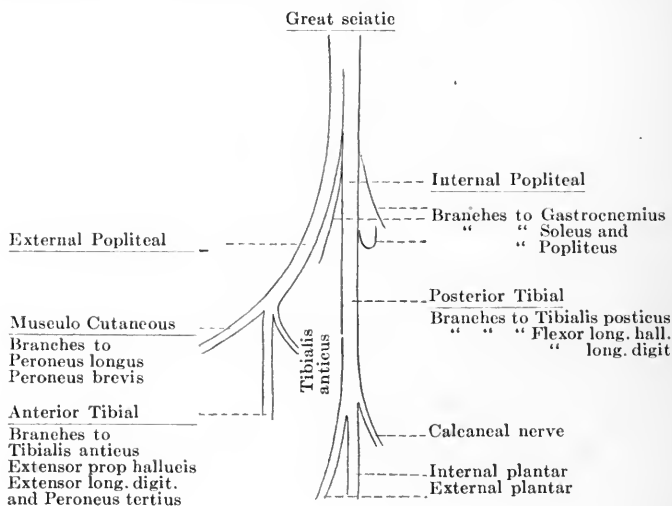
Fig. 26.—Diagram illustrating the terminal branches of the great sciatic
nerve, and their motor distribution.

14. *Cranial Nerves.*—Of these, only the facial and the spinal
accessory are of orthopedic interest. Injuries to the facial
result in paralysis of all the small muscles of the face, including
the orbicularis palpebrarum. When the spinal accessory has
been injured, there is some interference with abduction of the
arm, but owing to the double supply of the trapezius through
the cervical plexus as well as through the spinal accessory it
is not completely paralyzed. For a consideration of the other
cranial nerves, the reader is referred to any of the well-known
neurological text-books.

THE IMMEDIATE TREATMENT OF NERVE INJURIES

General Principles.—To prevent the development of deformity, maintain the maximum muscular tone, and create the most favorable opportunity for recovery, treatment of traumatic injuries to nerves should begin immediately after their occurrence.   The principle enunciated many years ago by Hugh Owen Thomas and constantly emphasized by Sir Robert Jones, must invariably receive the consideration of the surgeon.   This teaching of Thomas maintains that when a muscle, temporarily paralyzed, is constantly subjected to undue strain by a position of the limb which puts its fibres constantly on the stretch, the muscle itself degenerates and even when the nerve recovers it will fail to respond to the volition of the individual.

Thus, for instance, in the cases of musculospiral paralysis due to pressure on the nerve-either during narcosis or in deep sleep, the nerve injury will be repaired within six weeks.   If immediately after the paralysis has occurred the hand be properly splinted, so as to relax the fibres of the paralyzed extensors, the patient will be able to control his muscles as soon as the nerve paths have regained their normal conductive powers.   If, however, the hand be allowed to dangle during this period of nerve recovery, the patient will be unable to extend the hand voluntarily because the overstretched muscle fibres fail to respond to the nerve impulses.   In the nerve lesions of military practise the same rule applies as in those cases seen in times of peace.   In every instance of musculospiral paralysis or of injury to the anterior tibial, it is absolutely essential to splint the limb in such a way as to relax the affected muscles.   In the case of the ulnar nerve, other factors must be considered so that it is not safe to give a general rule applicable to all nerves.   In some instances, the surgeon must consider the tendency to deformity or to contracture and adjust his splint so as to prevent this from developing.

Recently it has been maintained (Stoffel) that the union of a divided nerve can be furthered by splinting the limb in such a position as to bring the nerve ends as near together as possible.   Thus, in division of the median nerve near the elbow,

4

the arm should be flexed; for division of the internal popliteal nerve, the leg flexed on the thigh. In experiments performed on monkeys, there was evidence to point in favor of this method of treatment, since in those cases of division of the median nerve in which the monkey's limb was kept in extension, no union occurred; whereas when it was flexed perfect union of the nerve resulted. As yet, there is too little evidence in human beings to confirm the correctness of this teaching, but on *a priori* grounds it appears to be reasonable, and provided there are no contraindications it would be well to adopt it.
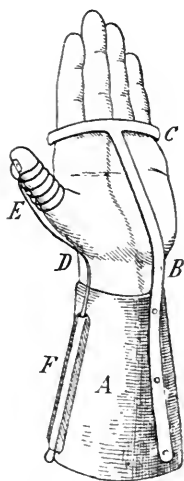
Fig. 27.—A splint for musculospiral paralysis. (*Spitzy.*) Note the effective abduction of the thumb produced by the wire spring. The bar "C" holds the proximal phalanges extended. The distal phalanges are left free.

Treatment of the Individual Nerves.—1. *Musculospiral.*—A light splint of plaster-of-Paris or metal or leather so applied as to hold the hand and thumb fully extended and reaching to the first interphalangeal joint should be applied in every instance. The two distal phalanges need not be extended, since, owing to the action of the interossei, the patient has them under voluntary control. The little additional freedom given by leaving these two joints free is a great convenience to the patient, who would otherwise have a completely helpless hand. I wish to emphasize the necessity of extending the thumb, the distal phalanx as well as the proximal, since the extensors of this finger are supplied by the musculospiral alone. In using the moulded plaster-of-Paris splint the lower end should be made sufficiently broad to hold the thumb in this extended position. The leather or metal splints should have a little side arm, easily constructed of a strong piece of wire, to maintain the correct position (see Fig. 27).

2. *Ulnar Nerve.*—In the case of the ulnar nerve there is no tendency to overstretching of the paralyzed muscles. On the contrary, that portion of the flexor profundus muscle supplied

by the ulnar nerve frequently undergoes a shrinkage, producing contracture of the fourth and fifth fingers. The splint should be applied so as to prevent this contracture by keeping the fingers straight. It is easily made of either plaster, wood, or cardboard.

3. *Paralysis of the Median Nerve.*—Here there is little danger of overstretching the paralyzed muscles since they are much more powerful than the corresponding extensors. Unlike

Fig. 28.—Light plaster-of-Paris splint reinforced with iron band to hold arm in abducted position, applicable to injuries of the deltoid or in after-treatment of contractures of the pectoralis major.

the ulnar nerve, however, there is little or no tendency to contracture, so that in the case of this nerve there is no necessity for a hand splint. If the injury lies near the elbow a splint, holding the forearm flexed, may, on Stoffel's hypothesis, promote union.

4. *Musculocutaneous.*—A light dorsal moulded plaster-of-

Paris splint or two pieces of metal held together at an angle of 70° should be applied to hold the forearm sharply flexed upon the upper arm, so as to relax the paralyzed flexors.

5. *Circumflex.*—The arm must be held abducted. In addition to the methods already given for injuries to the shoulder-joint, the simple splint shown in Fig. 28 gives excellent service. This is made in the following way:

Fig. 29.—An easily improvised plaster-of-Paris dorsal splint for paralysis of the anterior tibial nerve or for drop-foot due to any other cause. The bands running from the sole to the calf piece are made of strong webbing and are sewn tightly to the cotton flannel covering the plaster.

A piece of cotton flannel, reaching from the patient's iliac crest to the axilla and then forward to the elbow, is measured off. Its width should be twice that of the plaster-of-Paris bandages which are to be used to form the splint (the 6-inch size is the best). The bandages, after being immersed in water, are rolled backward and forward on the table so as to form two layers each about $\frac{1}{16}$ inch thick and corresponding in length to the strip of cotton flannel already prepared. Meanwhile, the surgeon has bent a strip of malleable iron about 10 inches long to form a right angle. This is placed between the two layers of plaster-of-Paris and the whole is enveloped by the two layers of cotton flannel. The plaster splint is applied to the patient's body and arm and fastened in place securely by a gauze bandage. After it has hardened, additional strips of webbing can be sewed to the cotton flannel so as to obviate the necessity of gauze bandages.

6. *Brachial Plexus.*—The arm should be kept abducted, the elbow flexed, and the hand extended. This is best done by a modification of the abduction splint shown in Fig. 28.

7. *Sciatic Nerve.*—The foot should be held at a right angle to the calf, since owing to the comparative weakness of the extensor muscles, pes equinus will rapidly result unless measures are taken to prevent it (see Fig. 29).

8. *External Popliteal and Anterior Tibial.*—The same splint is used as in the case of injury to the sciatic nerve.

9. *Musculocutaneous.*—The splint should be applied so as to hold the foot in moderate eversion (about 5° beyond the neutral position). Although the peronei are plantar flexors, it is not advisable to splint in the position of equinus for fear of developing a contracture of the Achilles tendon.

10. *Internal Poplietal.*—The foot should be splinted in moderate equinus position (about 110°) with downward pressure over the dorsum and upward against the ball of the foot so as to prevent cavus deformity.

11. *Posterior Tibial.*—Owing to the preservation of the nerves to the gastrocnemius and soleus, a splint is of no particular assistance in this type of injury.

In addition to splinting the extremity in the approved position, *massage* of the paralyzed muscles and *electrical stimulation* should be begun as soon as feasible.

CHAPTER III

INJURIES TO THE MUSCLES, TENDONS AND CUTANEOUS TISSUES

In the orthopedic treatment of injuries to these structures, it is impossible to formulate any rule of thumb. Two principles must be followed: (1) prevent contractures; (2) seek to maintain the function of the injured muscle and tendon. Frequently these two principles seem to run counter to one another and the only way to decide how to apply the splint with maximum benefit to the patient is by an intimate knowledge of the comparative strength of opposing groups of muscles. It is therefore advisable to consider the various types of injuries to the soft parts and to state what in my opinion is the position giving the best end result. In general it may be stated that the flexors and adductors tend to produce contractures when injured; therefore the limb should be so splinted as to keep them on the stretch. The extensors and abductors, on the contrary, tend to become overstretched; therefore subsequent to their injury the part should be splinted so as to give the maximal muscular relaxation.

Injuries to the Sternocleidomastoid or Muscles of the Neck (Fig. 30).—If untreated, these result in a torticollis, owing to the formation of scar tissue in the wounded muscles. The head is drawn toward the affected side and the chin tilts up toward the opposite side. It is therefore necessary to splint the head in just the opposite direction (see Fig. 31).

Injuries to the Trapezius or Shoulder Muscles.—These frequently result in a raising of the shoulder on the affected side (see Fig. 32), with a resultant scoliosis. A plaster-of-Paris dressing should at once be applied holding the two shoulders on the same level.

Injuries to the Deltoid.—In these there is no danger whatever of scar tissue contracture. On the contrary, the difficulty to

be avoided is an overstretching of the injured muscle which will result in an inability to abduct the arm. It must therefore be fixed in the abducted position by one of the methods already outlined.

Fig. 30.—Shell injury to the right side of the neck and of the back. This type of injury requires a plaster dressing holding the head toward the left side, otherwise a torticollis will result or an elevation of the right shoulder.

Injuries to the Pectoralis Major.—In the case of this muscle, the abducted position should be used, otherwise the arm will be bound closely to the body by the formation of scar tissue.

Biceps and Brachialis Anticus.—Injuries of these muscles, too, tend to result in contractures; therefore the arm must be kept extended. I have not found it advisable to hold the arm in the position of complete extension but rather to keep it at

an angle of about 160°, since otherwise the two portions of the flexor muscles are drawn excessively far apart and the union between them is too weak to be effective.

Triceps.—Here, too, the position should not be one of extreme flexion nor of extreme extension, but about midway between the two (140°).

Fig. 31.—Plaster dressing applied after severe injury to the right side of the neck. The window necessary for dressing the wound has not as yet been cut. Immobilization in this position is necessary to prevent development of torticollis, or of an elevation of the shoulder with a consequent scoliosis.

Flexor Muscles of the Forearm.—In injuries to these muscles the tendency to flexion contracture of the fingers is very marked and should be prevented by a light splint which holds the fingers extended.

Extensor Muscles of the Forearm.—In sharp contradistinction to the flexor muscles, there is no tendency whatever to contracture. Instead, the fingers and hand drop and the

patient later is unable to extend them.   The splint therefore must hold the hand and fingers extended.

Injuries in the Palm or on the Dorsum of the Hand.—As a rule, one projectile severs both the flexors and extensors and there is nothing to do except immobilize in the mid-position. If the extensors alone are divided, or the flexors alone, then the

Fig. 32.—Elevation of the left shoulder due to gunshot injury in the neighborhood of the left trapezius muscle.   A deformity of this type tends to occur when an immobilizing dressing, as shown in Fig. 31, is not applied.

fingers should be splinted so as to bring the tendon ends as near together as possible; that is, in the case of the flexors, by bending the fingers; in the case of the extensors, by keeping them extended.

In very rare cases of gunshot injuries it is possible to perform an immediate suture of divided tendons.   The methods of tendon suture are described on pages 171 and 175.   Here it is simply important to emphasize the necessity of splinting the

fingers after such a suture in the position of maximum relaxation so as to avoid tension on the line of suture.

Injuries to the Tendons of the Fingers.—There is usually very little to gain by a splint because the tendons become hopelessly adherent to the shattered bone. In rare instances, where the tendon alone is injured (this applies particularly to the extensors) I have found it helpful to splint the part in such a way as to bring the tendon ends together.

Injuries to the Gluteal Muscles.—In extensive injuries to these muscles it is well to abduct the thigh about 30° and keep it slightly hyper-extended, since otherwise the muscles tend to become weak and unable to keep the pelvis level when the patient is standing on the injured leg. That is, the same phenomenon is likely to occur after their injury as is found in cases of congenital dislocation of the hip where, owing to the elevation of the trochanter, the muscles are working at a mechanical disadvantage (Trendelenburg's sign).

Injuries to the Flexors of the Hip.—These muscles, on the contrary, tend to contract when injured, and a flexion contracture will probably result unless the thigh is kept fully extended.

Quadriceps Extensor.—The calf must be held extended, otherwise there will be a weakness of the extensor muscle.

Injuries to the Hamstring Muscles.—These tend to flexion contracture, and the knee must therefore be kept extended.

Injuries to the Gastrocnemius and Soleus Muscles.—In this type of injury, the foot rapidly assumes the position of equinus unless it is held at right angles by an appropriate splint (see Fig. 29).

Injuries to the Extensor Muscles of the Foot.—These are quickly overstretched when injured and the foot should therefore be held in the position of maximum dorsal flexion.

Injuries to the Skin Produced by Extensive Burns.—These will be considered chiefly in the second part of the book, where the work of the base hospital is given in detail. At the front, immobilization should follow the rules laid down for injuries to the muscles and tendons of the corresponding portions of the body.

CHAPTER IV

TRANSPORTATION OF THE WOUNDED

The transportation of the soldiers from the front to the base hospitals, although one of the most important problems of modern warfare, hardly falls within the scope of this book. From the orthopedist's point of view, the most important element in the success of the transportation lies in the effectiveness of the fixation method applied by the surgeon at the
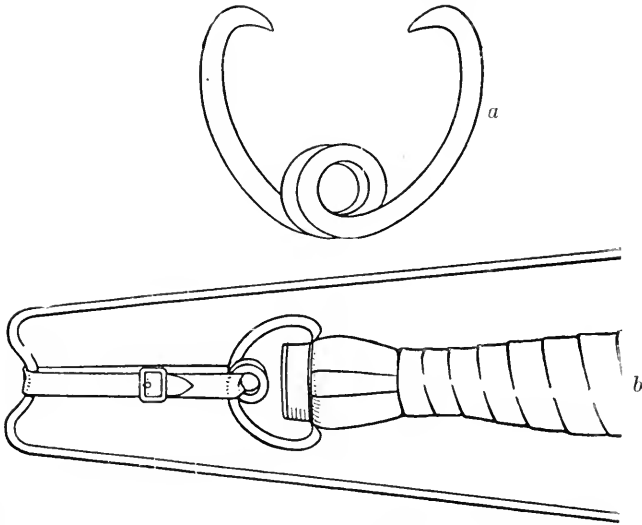
Fig. 33.—*a*, Tapson's spring clip. *b*, Showing use of Tapson's spring clip.

front. The most approved methods of transport will fail entirely if the surgeon has not done his work properly, and even the most cumbersome and old-fashioned vehicle will suffice if the part has been so splinted as to keep the injured limb absolutely at rest.

To bring the wounded from the trench to the bandage place or Hospital, a particularly ingenious device has been suggested

by Sergeant-Major Tapson. This is a spring clip which can be fastened directly to the boot of the patient in cases of fracture of the leg and when attached to the Thomas knee splint gives a most effective traction (see Fig. 33).
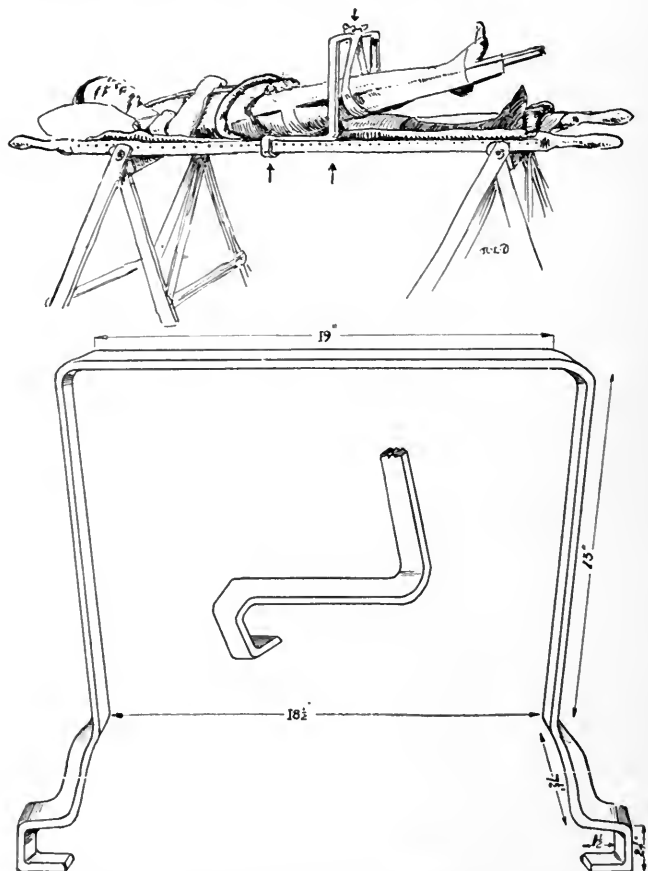
FIG. 34.—Richard's device for suspending fractured limbs during transport.

To prevent jarring of the limb during transport, Capt. Owen Richards has devised a frame illustrated in Fig. 34 by means of which the fractured limb can be lifted off the stretcher.

PART II

AT THE BASE HOSPITAL

CHAPTER V

THE TREATMENT OF BONE INJURIES

If the work at the front has been properly done the ortho-
pedic problem which confronts the surgeon at the base hospital
is much simpler than if ineffective methods have been followed.
In all instances his first duty is to take a roentgenogram of the
fracture, to determine the position of the fragments. If there
is a reasonably good alignment, with little shoretning, there is
no necessity to change the immobilizing splint. If, however,
interference with function is threatened, either by shortening
or by angulation, the position of the fragments must be
corrected.

In the fresh cases, this correction can almost always be
accomplished by non-operative procedures; in later cases,
when the bone fragments have already become firmly united,
open operation is frequently necessary to correct the deformity.

Non-operative Correction.—Much of what has already been
stated of the treatment of fractures at the front (see p. 18)
is applicable here. In the base hospital, however, the sur-
geon has a somewhat wider choice of methods, since he is not
hampered by the necessity of transporting the patient.

To overcome shortening, an anæsthesia is frequently necessary
in the later cases. By mean of block and pulley, or one of the
numerous extension tables, the muscular contraction is over-
come, the bones disengaged by lateral motion and an appro-
priate splint then applied. In recent cases, an anæsthetic is
seldom necessary, since 30 to 40 pounds extension will overcome
the shortening even in cases of several inches overriding in a

muscular individual.   The essential is effective application of
the traction.   Adhesive plaster does not suffice in cases of
marked shortening.   The bone itself must be gripped, either
by the nail-method, or better by the bone-tongs.   If the
fracture is near the ankle and the shortening is not readily
overcome, tenotomy of the Achilles tendon will aid materially.
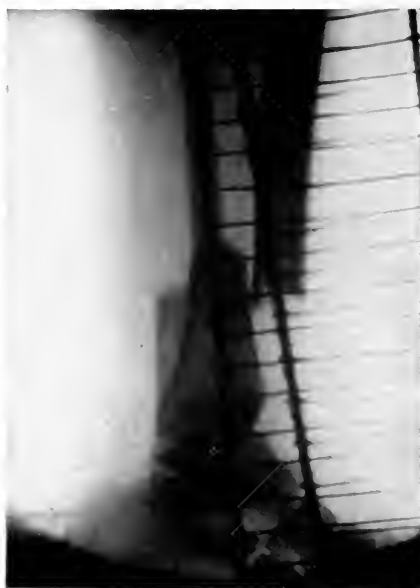
Fig. 35a.—Compound fracture of both bones of the calf with 2 inches
overriding.   The usual extension methods failed to overcome the deformity.
For effect of fracture with bone-tongs, see p. 63.

Fig. 35 (a and b) illustrates the effect of the bone-tongs traction
combined with tenotomy in a stubborn case of overriding
which had been treated for over a week without effect by
other methods of extension.   The final anatomic and functional
result in this case was excellent.

The longitudinal extension should be supplemented in suit-
able cases by lateral traction to overcome lateral deviation
or by a rotating pull to correct a torsion of the fragments.
A comparatively slight weight—2 to 5 pounds—is usually suffi-

cient. The rotating traction is applied by a strip of adhesive passing about the limb in the desired direction as indicated in the diagram (Fig. 36). Every lateral pull requires counter-traction. The cords to which the weights are attached pass over pulleys fixed to the sides of the bed. A convenient addition to the equipment for extension is the "Balkan" frame, serving for the attachment of pulleys at any desired point.

FIG. 35b.—Compound fracture of both bones of the calf with 2 inches over-riding, five days after inserting the "bone-tongs." The original traction of 40 lb. was decreased to 20, allowing the bone ends to come into contact, with final excellent anatomical and functional result.

One of the most perplexing difficulties in the traction treatment of extensive compound fractures of the femur is the prevention of adhesions to the quadriceps femoris, and consequent stiffness of the knee. The problem has been solved by Ansinn,[1] who has devised a method of extending the thigh and at the same time mobilizing the knee. By reference to Fig. 37 the essential principle is made plain. The apparatus

[1] Buckner (see Surgery, Gynecology and Obstetrics, April, 1917) has also devised an apparatus closely resembling in principle that of Ansinn.
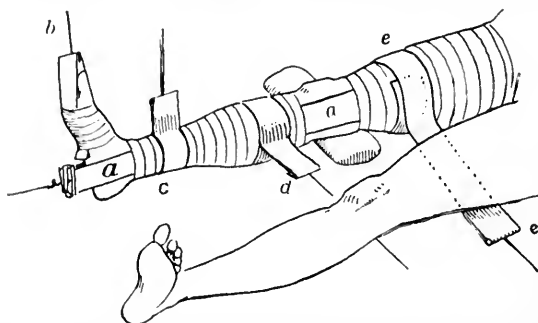
FIG. 36.—Diagram (Bardenheuer) illustrating the attachment of adhesive strapping for extension, lateral traction, rotation, etc. *a*, Longitudinal traction; *b*, traction to prevent drop foot and to lift heel from bed; *c*, pull toward ceiling to correct backward displacement; *d*, transverse traction to correct lateral displacement; *e*, rotatory pull to correct external rotation.
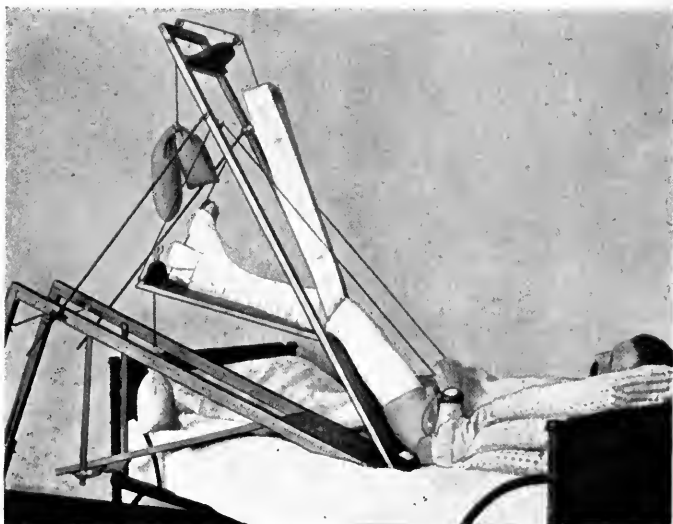
FIG. 37.—Photograph illustrating the Ansinn method of traction in cases of fracture of the femur, combined with mobilization of the knee joint. For a detailed description see page 65.

consists of a jointed inclined plane. The joint corresponds to the knee. The upper end of the plane supports the injured thigh, which is extended by adhesive plaster, or in severe cases by the bone-tongs affixed to the condyles of the femur. To the calf, a separate adhesive plaster extension is applied. This is fastened to the lower end of the inclined plane, whereas the thigh is fastened to an immovable upright or to a bar affixed to the lower end of the bed. It is clear

FIG. 38.—Modification of the abduction splint (Fig. 4) to encourage motion of the elbow. The patient is bending forward so as to show the transverse bar applied near the wrist which supports the hand during flexion and extension of the elbow.

that the calf can now be flexed or extended without in any way interfering with the constant traction exerted upon the thigh. By a simple pulley arrangement, the patient can alter the position of the leg himself. Ansinn has modified the system by attaching his apparatus to a motor which very slowly raises and lowers the calf; a movement of 90° requires about six hours. The results from this method are excellent in cases where any other system of extension would tend to result in

5

disastrous adhesions.   A similar idea is applicable to fractures
of the humerus, by modifying the abduction splint so as to
allow motion at the elbow (see Fig. 38).

The Ansinn method of extension has a further advantage
to which Zuppinger's recent studies in muscle physiology have
attracted attention.   Zuppinger demonstrated that by flexion
at the thigh and at the knee, sufficient muscular relaxation

FIG. 39a.   FIG. 39b.

FIG. 39a.—Fracture of the upper third of femur, showing characteristic
angulation.   39b. The same subsequent to correction by the abduction
method described on p. 67.

could be secured to permit correction of shortening by about
half the traction necessary when the joints are fully extended.
This fact can be utilized not only for the Ansinn method, but
for other cases in which this is not indicated, by bending the
Thomas splint at the knee and suspending it from the Balkan
frame (Besley in J. A. M. A., Jan. 12, 1918, Silver, Lower
leg fracture splint, Blake and Bulkley, Surg., Gyn. and Obst.,
March, 1918).   The principle is of course the same as

that utilized in the Hodgen's splint, with the added advantage of a more effective method of traction.

Correction of Angulation.—Not only in the recent cases, but even in those which are six or eight weeks old, the angulation can usually be corrected by simple manipulation. In one patient, even after three months I was able to correct the angular deformity without incision (Fig. 39). This is probably due to the fact that the healing of gunshot injuries to the bone is distinctly slower than of fractures produced by indirect violence. The method of correction is simple. Take, for instance, an angulation of a fracture in the upper third of the femur. The characteristic deformity is an angle pointing outward, due to the adduction of the lower fragment. The patient is placed upon a hip rest, a stout strip of webbing, 4 inches in width, is passed about the upper fragment and fastened firmly to any fixed point on the opposite side of the patient's body. The operator then grasps the lower fragment above the knee, and while the assistant exerts strong traction in the longitudinal direction, he slowly forces the lower fragment outward until its longitudinal axis lies in the same line as that of the upper fragment. While it is held in this position by an assistant, a plaster spica, extending from the nipple to the toes, is applied; or the Jones abduction splint can be used.

In fractures of the mid-third of the femur, a backward angulation is frequently present, owing to a sag of the bones through the improper application of straps or to improper technic in putting on the plaster splint. This should be corrected by traction toward the ceiling at the point of angulation. For this purpose it is convenient to have a block and pulley attached to the ceiling of the operating room; a broad webbing band is passed around the femur and attached to the rope which passes over the pulley. By depressing the lower fragment, the angulation is overcome. The webbing band is left in place during the application of the plaster.

Angular deviation of fractures of the humerus can usually be corrected simply by changing the angle of the abduction splint; when the angle of deviation points outward, increase the abduction; when the angle points inward, decrease the abduction, until the fragments are properly aligned.

Operative Correction.—In the later cases when the bones are firmly united by callus, recourse must be had to osteotomy. This operation should not be performed until all signs of infection have subsided, since otherwise disastrous results may ensue. The principle of the operation is removal of a wedge of such a shape and size that by abduction or adduction of the lower fragment the proper alignment can be secured. I have found it of assistance in these cases to make an accurate tracing of the anteroposterior roentgenogram and operate first upon this tracing with a pair of scissors to determine the exact size of the wedge to be removed.

When the angulation is combined with marked shortening, this method does not give as good results as an oblique division of the bone in the line of callus, followed up by energetic traction. This form of treatment, however, is more time-consuming and should therefore not be applied when the wedge-shaped osteotomy suffices to correct the deformity.

The Duration of Immobilization.—No specific time can be given for any one type of fracture, but each case must be judged on its own merits. The x-ray is the most important guide in determining when immobilization may be discontinued. As a rule, the healing does not occur as rapidly as in fractures due to indirect violence, and even when the x-ray shows a distinct callus formation and palpation indicates an apparent union the bone must be carefully protected against all undue strain, since it is readily refractured or, in the case of the lower extremity, bent by the superimposed body weight. It is therefore wise, after removing the immobilizing splint, to apply some protective apparatus to the injured bone. This should be as light as possible and allow as much freedom of motion of the adjacent joints as is consistent with the necessary protection of the fracture. Fig. 40 illustrates a light plaster-of-Paris dressing applicable to a healing fracture of the upper third of the humerus. The plaster is applied, without any padding, over a piece of stockinette and is held in place by the strip of flannel passing around the patient's chest.

In fractures of the radius, with extensive shattering of the bone, the patient must be warned against too early pronation. I have found it advisable, whenever possible, to apply a leather

splint so constructed as to allow full extension and flexion at
the elbow and wrist, but to prevent pro- and supination.
This consists of two leather cuffs, one attached to the upper
arm and one to the forearm, held together by two lateral
steel supports which are jointed at the elbow.
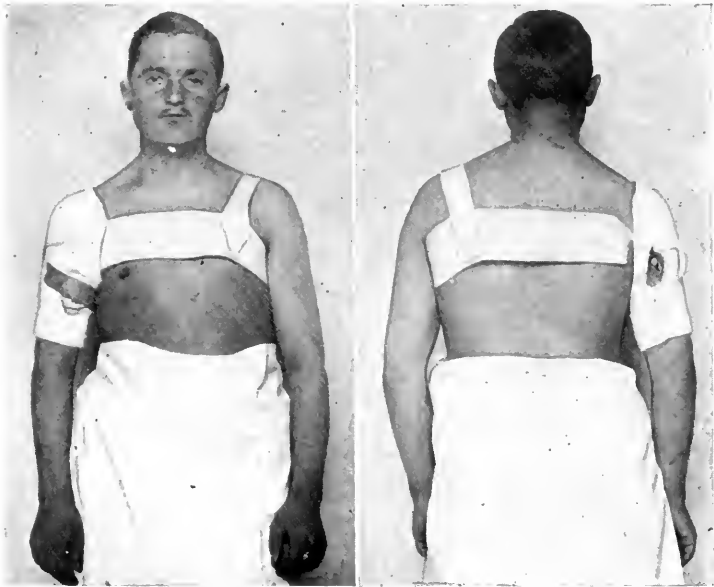
Fig. 40.—Anterior and posterior views of a simple plaster dressing appli-
cable to the after-treatment of extensive fractures of the upper end of the
humerus. The splint allows a moderate range of motion and at the same
time guards the bone against refracture.

For fractures of the femur, it is not advisable to allow full
weight-bearing when the patient first gets out of bed. The
Thomas splint can be modified effectively to remove the body
weight from the bone; this is done by running the lower
transverse bar through a slot in the heel of the boot. The
uprights must be a trifle longer than the length of the patient's
leg so as to prevent his heel from quite touching the ground.

When the Thomas splint is not to be had, plaster can be used for the same purpose. The usual spica is applied from the lower ribs to the ankle, particular care being taken to mould an accurate support for the tuberosity of the ischium (see p. 35). Into the lower portion of the plaster, a strong bar of iron bent so as to form a loop, projecting 4 inches beyond the patient's heel, is incorporated by several extra turns of the plaster bandage (see Fig. 20). The patient can walk in this without bringing his weight to bear on the bone.

In fractures of the bones of the calf, I have never found it necessary to remove weight-bearing entirely, since sufficient support is given by a light circular plaster-of-Paris dressing or by a light splint consisting of two steel uprights affixed to the patient's boot. When there is any tendency to a valgus deformity, the outside iron and Thomas heel, as advocated by Jones, are indispensable.

Methods of Mobilization.—In almost all gunshot injuries to the bones, adhesions form during the period of immobilization. We have already seen how these can be prevented in the case of fractures of the femur and of the humerus. In many cases, however, despite the earliest possible discontinuance of immobilization, adhesions are present, preventing the free play of the muscles and hindering the motion of the joint. Their treatment will be considered when discussing injuries to joints.

Non-union of Fractures.—This occurs more frequently after gunshot injuries than in other types of fractures, owing to the extensive loss of osteogenetic tissue commonly caused by the projectile. Care on the part of the surgeon in conserving all tissues capable of bone regeneration, frequently produces good results under circumstances which at first seemed hopeless. Thus Fig. 41 illustrates an injury to the humerus, in which the splinters of the shaft lay fully exposed at the bottom of a severely infected extensive wound. None of the bone fragments were removed, although many of them were attached by only a few shreds of periosteum. Within three months solid bony union had occurred.

In many instances, however, despite this attempt to conserve, non-union results. The methods of treatment do not

differ from those employed in the pseudo-arthroses subsequent to fractures produced by indirect violence.

Non-operative Treatment.—When it is possible without operation, to bring the bone ends together, an attempt to bring about union should be made:

Fig. 41.—Gunshot injury to the upper end of the humerus. None of the bone splinters were removed, although the wound was severely infected. Healing in ten weeks without shortening or other deformity.

(*a*) By vigorous rubbing of the bone ends so as to stimulate osteogenesis, followed by

(*b*) Absolute immobilization in a splint which exercises uniform pressure at the site of the fracture. In the case of the

upper extremity where moderate shortening is of little significance the splint should press the bone fragments together, even if there is a hiatus of 1 or 2 inches between them. In the lower extremity the splint should be so constructed as to allow weight-bearing, at the same time supporting and immobilizing the fragments, since the body-weight frequently conduces to bone production.

(c) In addition, the Thomas method of "hammer and dam" should be vigorously followed. A rubber compression bandage is applied above and below the site of injury, and the periosteum traumatized with a hammer.

This non-operative treatment should be pursued for at least three months. If then there is no improvement, operation is indicated.

Operative Treatment.—Non-union of fractures is best treated by bone-implantation. Few subjects in recent years have attracted more attention than this, and much careful experimental work has been done to decide the fate of the graft and to determine the most physiological operative procedure. The classical research of Ollier has been confirmed by Axhausen, who showed conclusively the superiority of autoplastic transplanted bone to homoplastic or heteroplastic, of living bone to dead, of periosteal-covered to bone stripped of the periosteum. The osteogenetic importance of the periosteum has been challenged by Macewen ("The Growth of Bone," 1912). On the basis of animal experimentation and clinical experience he maintains that the periosteum acts merely as a limiting membrane and that the bone growth comes from the bone cells which possess a vegetative capacity fully as great as that of the epithelial cells. An experimental study of Macewen's work, however (Mayer and Wehner: Archiv für Klinische Chirurgie, Bd. 103, Heft. 3) has created some skepticism as to the correctness of his views. To test Macewen's claim that there is an outpouring of osteoblasts from the bone after the periosteum has been removed, Mayer and Wehner performed the following experiment: The periosteum was stripped from the surface of the tibia (rabbits and dogs were used), and a small cap of glass or steel fastened firmly to the surface of the

bone, so as to exclude the periosteal cells from the denuded surface of the tibia (see Figs. 42 and 43). Were Macewen's view correct, bone production would occur beneath the cap.
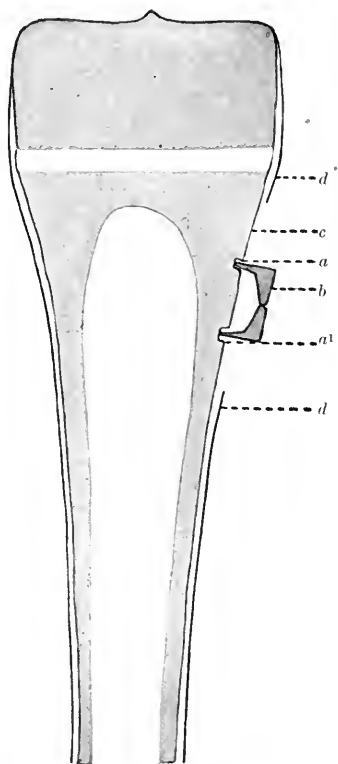
Fig. 42.—Schematic, longitudinal section of tibia, illustrating the principle of Mayer and Wehner's "cap experiment." The cap was fastened directly to the denuded cortex of the tibia allowing an ample air space into which osteoblasts could migrate, were Macewen's theory as to their genesis, correct. a, Groove in the cortex, to which the cap, b, was fastened by a wire (see Fig. 43); c, the cortex denuded of periosteum; d, periosteum.

The experiment showed that in all those instances, in which the periosteal cells were completely excluded by the cap, no regeneration of the bone took place, whereas in those instances

in which, owing to the presence of a minute gap between the cap and the bone, the periosteum was given a chance to grow in, osteogenesis occurred (see Figs. 44 and 45).   The further experiments of Mayer and Wehner emphasized the correctness

Fig. 43.—Photograph illustrating the manner of attaching the little caps to the denuded surface of the tibia.   This experiment of Mayer and Wehner tested the osteogenetic function of the cortical bone, and proved the incorrectness of Macewen's contention that the osteoblasts issue from the interior of the bone.

of Ollier's teaching: that the most important osteogenetic cells are those lying between the outer fibrous layer of the periosteum and the surface of the bone—the so-called cambium layer of the periosteum.   The osteogenesis observed in cases of bone

Fig. 44.—Microscopical cross-section of the tibia illustrating the result of Mayer and Wehner's "cap experiment." Specimen recovered 48 days after the operation. The cap successfully prevented the ingrowth of regenerated periosteal cells and consequently no bone growth whatever occurred beneath it, in marked contrast to the excessive production of new bone on the outer surface of the cap. *a*, Denuded cortex beneath the cap; *b*, the grooves into which the cap was firmly fastened; *c*, newly formed bone on the outside of the cap; *d*, regenerated periosteum; *e*, detritus.
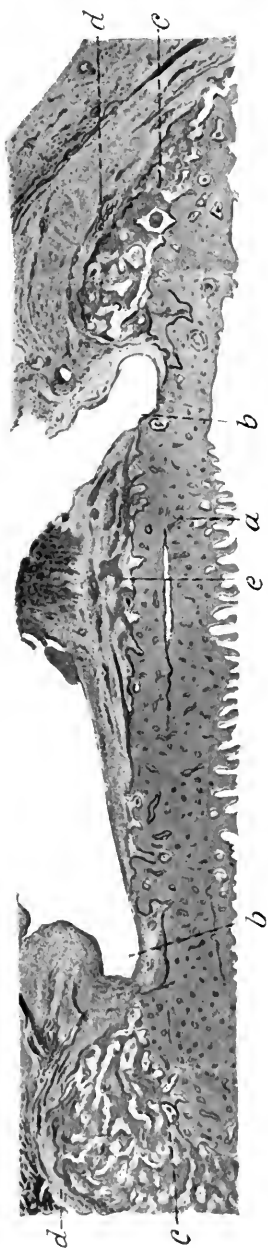
Fig. 45.—Microscopical cross-section of the tibia illustrating the effect of Mayer and Wehner's "cap experiment." Specimen recovered 15 days after the operation. On one side the cap was not fastened sufficiently firmly to prevent the ingrowth of regenerated periosteum. A formation of new bone has therefore occurred beneath the cap. a, Cortex of tibia; b, grooves into which the cap was set. Note that on the left side the periosteum has obliterated the groove; c, new bone formation outside of cap; d, regenerated periosteum; e, newly formed bone beneath the cap.

transplantation, macroscopically without periosteum, is unquestionably due to the adhesion of these osteogenetic cells to the surface of the graft. Endosteal cells of the marrow cavity and of the Haversian canals are also capable of osteogenesis, though to a diminished degree.

Animal research and secondary operations on human beings, coupled with autopsy findings have given a clear conception of what occurs after a transplantation of living bone. The

Graft

Fractured
spinous process
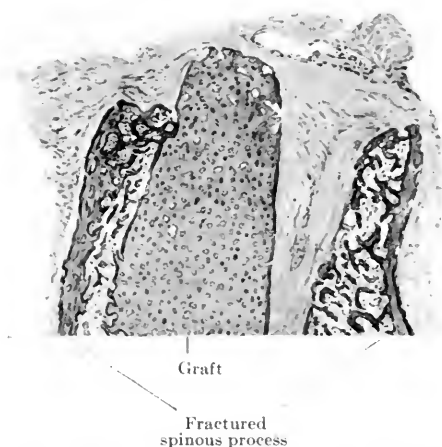
FIG. 46.—Cross-section of a tibial graft inserted between the halves of a cleft spinal process. Magnification, ×4. Specimen recovered 60 days after operation. For the higher magnifications, see the following figures.

theory that the transplanted bone acts merely as a scaffolding is as incorrect as Macewen's conception of the bone cells proliferating with the rapidity of epithelial transplants. Figs. 46, 47, 48, 49 and 50 illustrate the course of events. They were derived from a case of transplantation of the tibia for spinal disease (typical Albee operation in male 40 years old). Death occurred 60 days after the operation. The greater part of the transplanted bone shows no evidences of life. On the surface where the tip of the transplant projects into the sur-

—Connective
tissue
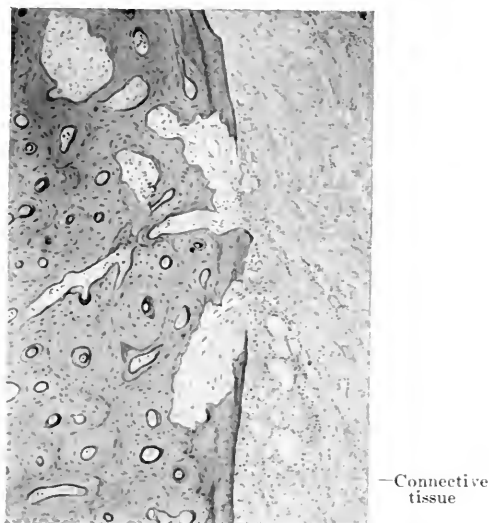
Graft surface, showing absorption

FIG. 47.—Camera lucida drawing of microscopical section of the transplanted bone, at a point where it projects into the soft parts. Section shows extensive bone absorption due to the ingrowth of capillaries.

Young, newly-formed bone on surface of graft in contact
with the fractured spinous process

Marrow
cells of—
fractured
spinous
process

Dead
—bone of
graft
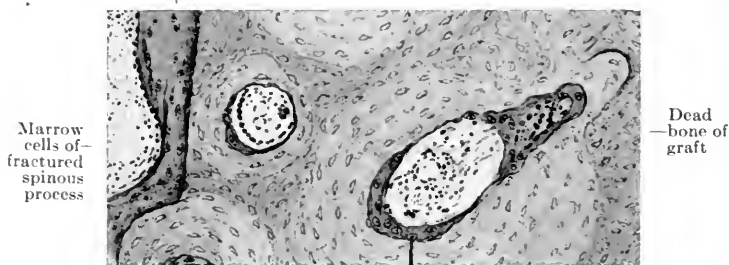
Young, newly-formed bone about a Haversian canal

FIG. 48.—Camera lucida drawing of microscopical section of the transplanted bone where it is in contact with the cancellous tissue of the split spinous process. In this section, in contra-distinction to the preceding, there is conclusive evidence of new bone formation, not only on the surface of the graft, but also surrounding the Haversian canals. In these are visible the capillaries which have invaded the graft and typical osteogenetic cells which have evidently been derived from the adjacent bone of the spinous process.

rounding connective tissues, bone destruction has taken place.
The bone cells have lost their normal staining qualities and
the lacunæ are empty. In that portion of the graft, however,
where cancellous bone was transplanted, a large proportion
of nuclei have retained their normal appearance. Where the

Young, new-formed bone on periosteal surface of graft

Connective tissue

Graft (dead bone)
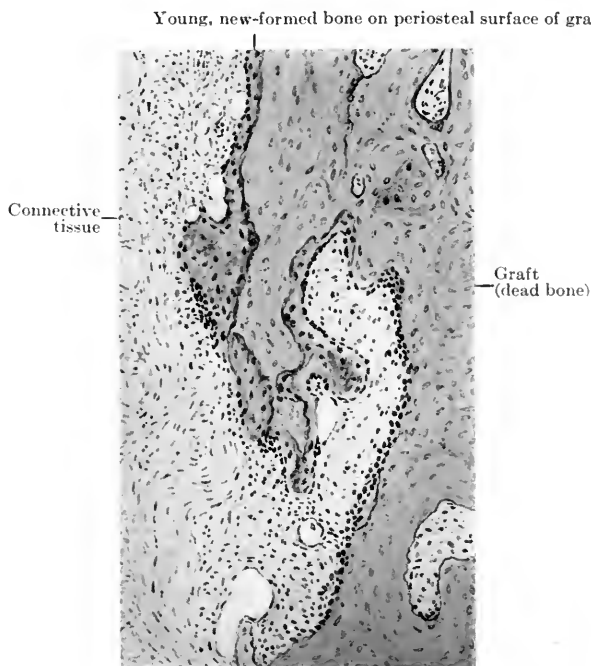
FIG. 49.—Camera lucida drawing of the periosteal surface of the bone
graft. Here, although there is no contact with the spinous process, a new
formation of bone has occurred, unquestionably due to the osteogenetic
function of the transplanted periosteal cells.

graft is in intimate contact with the living bone of the spine
a deposit of young osseous tissue is visible on the surface and
the enlarged Haversian canals near this area are surrounded
by zones of similar young bone differing sharply in appearance
from the old bone of the graft.

In contrast to this picture of inactivity on the part of the transplant is the active growth of bone occurring on its periosteal surface.   Here, even though there is no intimate contact with the cleft spinous process, a layer of new bone has formed.

Summarizing these facts, it is clear that the graft acts in two ways: *first*, passively, as a kind of scaffold, for the ingrowth of bone derived from the osteogenetic tissues into

Marrow of fractured spinous process

The graft showing numerous well-stained nuclei of bone cells

Young bone on surface of graft
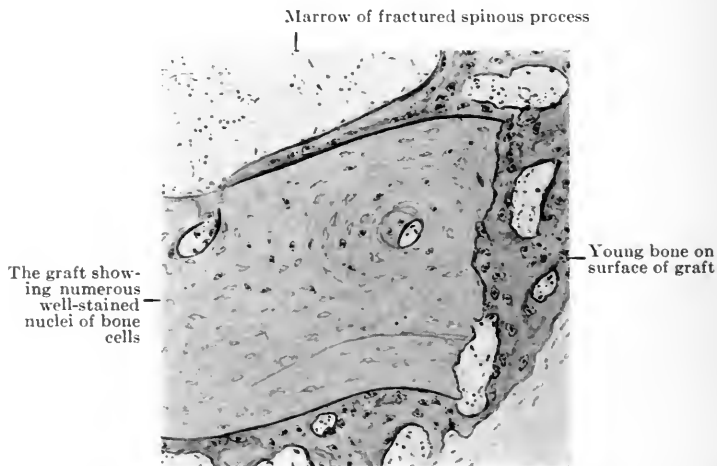
FIG. 50.—Camera lucida drawing of a part of the cancellous bone forming the deeper layers of the graft.   In this cancellous bone many nuclei have retained their normal staining capacity—microscopic evidence that they are still alive.

which it has been implanted; *second*, as an active factor by the osteogenetic function of its periosteal and endosteal cells. Most of the bone cells die, but some of them, particularly those of the cancellous tissue, live.   These, however, do not show evidences of marked proliferative capacity, as do the periosteal cells, although the microscopic picture in some instances is suggestive of their power of amitotic division.

An important element in the success of bone grafting is the power of functional development inherent in bone (Wolff's law).   It has been shown that bone will respond to abnormal

stress and strain by changes in its architecture to meet the
new mechanical conditions. Fig. 51 illustrates an instance of
this adaptability of bone. It is a cross-section of a tibial
transplant for Pott's disease (Albee operation). The cortex
of the tibia was transplanted. At autopsy, a year and a half
later (death due to amyloid disease) the bone was found to
have assumed the tubular form with cortex and medullary
cavity, exactly as in one of the long bones.
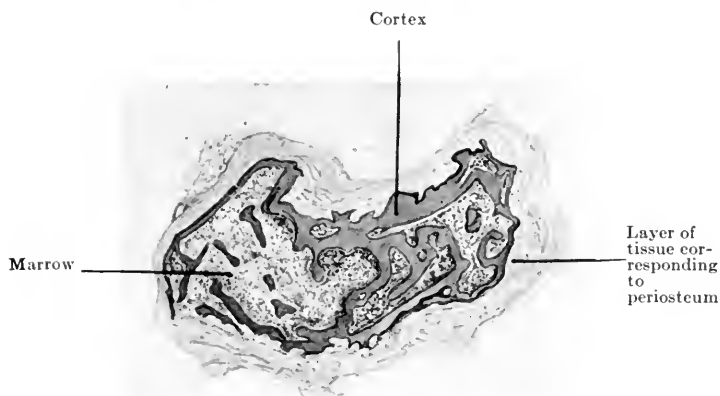
Fig. 51.—Microscopical cross-section of a cortical graft from the tibia
inserted by the Albee technique in a case of Pott's disease. Specimen recov-
ered 1½ years after operation. The cortical graft has assumed the shape
of a tubular bone with cortex, marrow cavity and periosteum. The specimen
illustrates the functional adaptation of the graft to its new environment.
(*Wolf's Law.*)

The operative technic must be based upon a knowledge
of the laws of bone regeneration. That method is to be con-
sidered most physiological in which the osteogenetic elements
of the transplant are afforded the best opportunity for devel-
opment, and in which the significance of the underlying me-
chanical laws are properly appreciated. These requirements
are in my experience best met by the technique devised by
Albee (see "Bone-graft Surgery," W. B. Saunders Co.). The
essential principle in this method is the implantation of the

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graft in such a way as to bring each one of its constituent parts into intimate contact with the corresponding elements of the recipient bone.

Application to Gunshot Injuries.—Exactly the same technic is applicable to these as to the pseudo-arthroses produced in other ways. In two respects only must great caution be

a   *b*

FIG. 52.—Pseudarthrosis of the ulna subsequent to gunshot injury.   *a*, Three weeks after insertion of a graft.   *b*, Two months later showing fracture of the graft.   Healing by callous, produced by osteogenetic function of the engrafted bone.

exercised: *first*, operation must be postponed until all signs of infection have been absent 4 months, otherwise healing will occur in only a small percentage of the transplants; *second*, more than the normal precaution must be used in the after treatment, since, owing to the extensive loss of bone and to the scar formation fracture of the graft can easily occur (see Fig. 52).

FIG. 53a.—A gunshot injury of the lower portion of the humerus. The diastasis of 2 in. was successfully bridged by a bone transplant as shown in Fig. 53b.

FIG. 53b.—Pseudarthrosis of humerus due to extensive loss of substance produced by gunshot injury. a, Three months after the injury. b, After a bone graft by the Albee method. Healing by primary union occurred despite the presence of shell fragments. Particular care was taken to plan the operative incision so as to avoid these possible foci of infection.
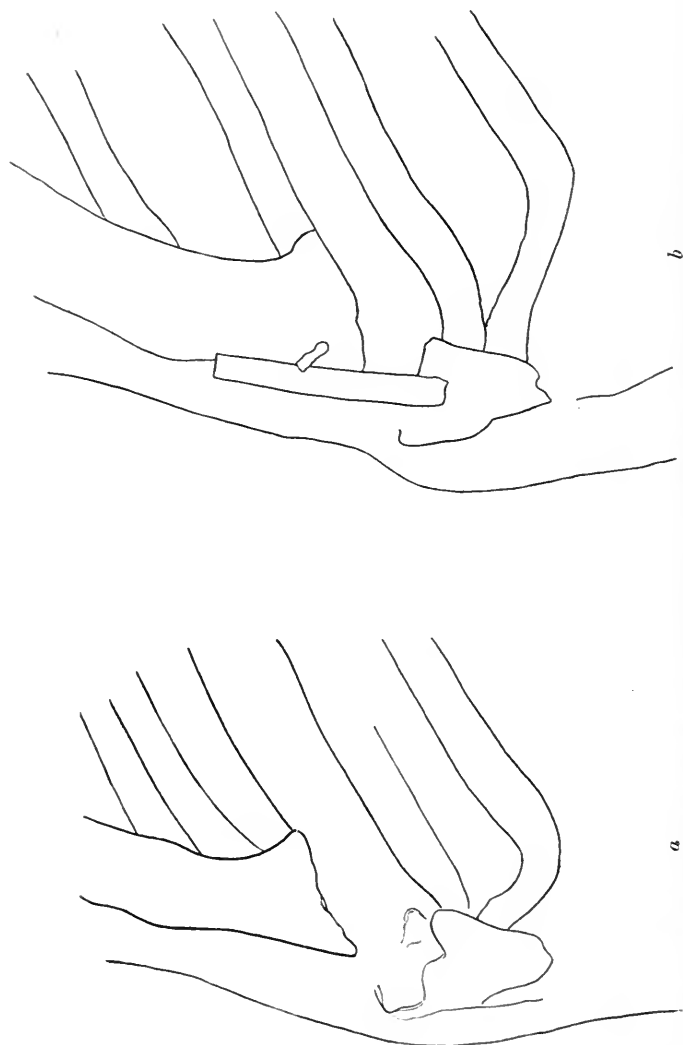
Fig. 54.—*a*, Tracing of roentgenogram of pseudarthrosis of the sternum produced by extensive gunshot injury. Respiration caused the patient intense pain because of the rubbing of the fragments against one another. *b*, the same, subsequent to the implantation of a strong tibial graft. The patient's pain disappeared immediately after the operation.

Prognosis.—In gunshot injuries the operator cannot hope for primary union and healing of the graft in all cases. In a series of forty bone grafts successful healing occurred in 65 per cent. This average would probably have been distinctly bettered had I realized from the outset the necessity of postponing the operation for several months after every indication of infection had disappeared, since in the last 20 cases, in which this rule was closely observed, healing occurred in 90 per cent. (See Figs. 53 and 54.)

CHAPTER VI

JOINT INJURIES

This book is concerned essentially with gunshot wounds. Therefore, I shall not deal with those traumatic injuries to joints which are frequently seen in times of peace, such as sprains, lesions of the semilunar cartilages, dislocations, etc., nor with diseases of joints, although, of course, the soldier is more liable to these joint troubles than the civilian. The military surgeon must be as well acquainted with their treatment as with that of gunshot injuries.

Nor are we concerned with the immediate surgical treatment of gunshot injuries to the joints—the technic of drainage, methods of resection, etc. In passing, however, I want to emphasize one important fact relative to the treatment of infected gunshot wounds of the hip with involvement of the femoral head: Effective drainage can be secured only by resecting the femur. That this operation is not a crippling one is evidenced by Fig. 55, which shows the result after resection of the head, neck and a part of the great trochanter. From the orthopedic point of view the after-treatment is of importance. To prevent the shortening which injudicious posture would cause, the thigh should be abducted sufficiently to prevent the trochanter from slipping upward. A plaster spica is not necessary, since the position is easily maintained by traction in the abducted direction.

When discussing the work at the front, the position in which to immobilize gunshot injuries to the joints, was considered in detail. In the base hospital, the immobilization should be continued until all danger of infection has subsided.

In employing *methods of mobilizing joints,* it is important to distinguish between those cases in which there has been destruction of the joint cartilage and those in which the limita-

tion of motion is due merely to adhesive bands. In the case of the latter, vigorous methods are possible, which if applied to the former would result disastrously. I shall consider first:
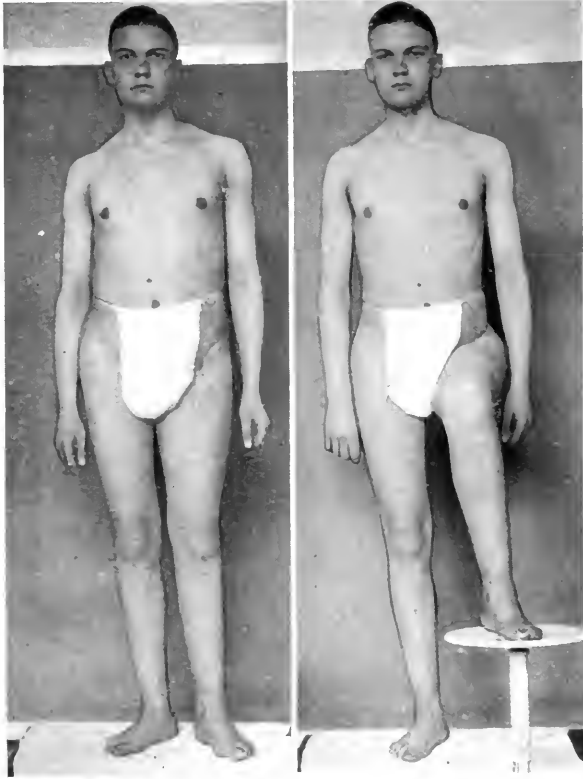
FIG. 55.—Result six months after excision of the head, neck and portion of the great trochanter of the left femur due to extensive gunshot injury of the hip. Shortening of only 1 inch. Voluntary flexion and abduction almost to the normal range. Patient able to walk four hours without fatigue.

Treatment of Adhesive Bands, Either Within or in the Immediate Proximity of the Joints, in cases uncomplicated by infection. Under these circumstances, it is safe to rupture the adhesions. Although an anæsthetic is useful in

securing muscular relaxation and in sparing the patient pain, in many instances it is preferable, from the patient's point of view, to avoid the risk of anæsthesia.   Whether with or without an anæsthetic, the methods employed are the same.
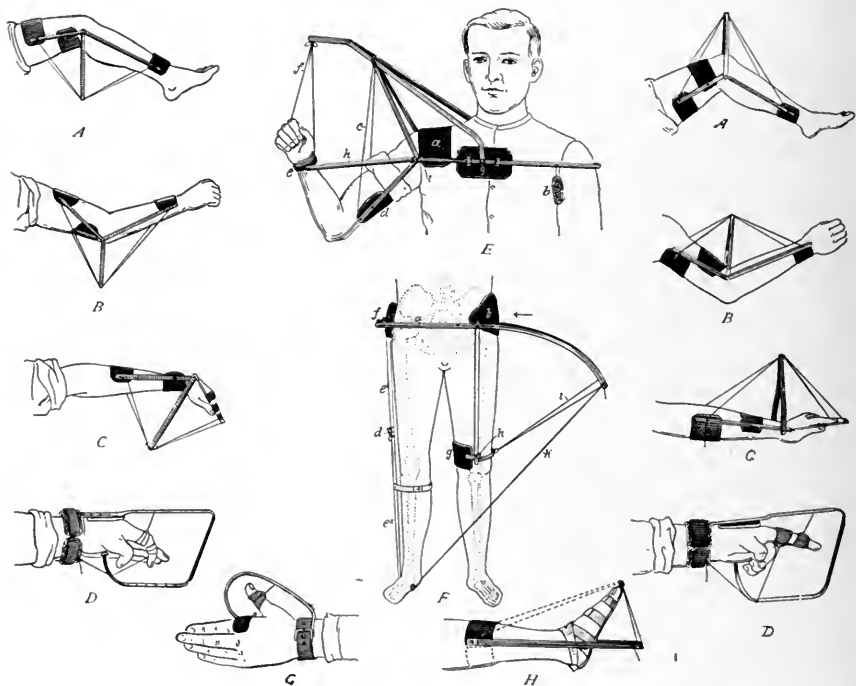
Fig. 56.—Schede splints for the after-treatment of injuries in the neighborhood of joints. By simply changing the position of the intermediate bar, the splints can be used to produce either extension or flexion.   The traction is exerted by means of a stout cord, which the patient himself easily learns to adjust.

Steady force is applied to the extremity first in one direction, then in another until the adhesive bands are ruptured; the bone should be protected during this procedure by a splint or by the hand of the operator.   The work is not to be considered complete until joint motion is free in all directions.

For each joint, certain grips are of particular value in break-

ing up the adhesions. For a knowledge of this medical jiu-jitsu, I am particularly indebted to Sir Robert Jones. In breaking up adhesions in the neighborhood of the shoulder, the scapula should be fixed by an assistant, who grasps the patient firmly from the opposite side of the body. The operator grasps the humerus a short distance above the condyles, and with one hand steadying the head in the axilla forcefully and

FIG. 57.—The Schede splint applied to an injury on the anterior aspect of the elbow joint. The traction exerted by the cord gradually overcomes the flexion contracture.

gradually abducts. When motion with the scapula fixed is possible to 90°, the assistant should let go, so that the full range of abduction can be tested. With the scapula again fixed, rotary movements are performed, and with the arm abducted 90° it is brought forward and then forced backward. One carefully executed motion in each direction suffices to break up the adhesions.

At the elbow, the most usual adhesion is one preventing extension. The surgeon brings the patient's upper arm against

his own chest, holding it firmly there with one hand, while the other, grasping the patient's arm just above the wrist, extends the forearm.

FIG. 58.—Roentgenogram of injury to the elbow joint.   The result of the arthroplastic operation is shown in Fig. 59.

To secure pro- and supination, the operator grasps the patient's hand and locks the third and fourth fingers on either side of the lower end of the radius and of the ulna.   Rotary movement of the surgeon's hand produces a rotation of the radius about the elbow.

At the wrist, one frequently finds a flexion deformity due to adhesions. The operator grasps the patient's arm just above the styloid process of the radius and brings the ball of the thumb of the opposite hand against the carpal bones. The pressure of the two hands toward one another forces the carpus and metacarpus into the extended position.

Fig. 59.—Arthroplasty of the elbow subsequent to ankylosis due to gunshot injury. Two photographs on one plate illustrating the range of flexion and extension. For the roentgenogram of this patient see Fig. 58.

In the lower extremity, when attempting to restore the full range of abduction, the pelvis should be fixed by abducting the opposite leg; when overcoming a flexion contracture, it should be fixed by flexing the opposite thigh forcibly on the body.

For the knee, particular care must be exercised, since the lower end of the femur is easily refractured unless carefully splinted before correction is attempted. To break up adhe-

sions to the quadriceps extensor, the calf is grasped above the ankle and with a suitable pad in the popliteal fossa the surgeon's weight is brought to bear in such a way as to force the ankle toward the ground.   A strong webbing band holding the thigh to the table is of assistance.

Mobilizing Methods Following Infectious Processes or Injury to the Cartilage.—In these cases forcible attempt to

Fig. 60.—Roentgenogram of wrist fully ankylosed as sequence of severe gunshot injury to the lower end of the radius and to the carpal bones.   For result of treatment see Fig. 61.

move the joint is contraindicated, because there is danger of re-establishing infection or of stimulating increased bone production at the site of the joint injury.   Gentle methods must therefore be pursued.   I have found the simple effect of gravity to be the most efficacious.   In the case of the shoulder which has been immobilized in the abducted position, removal of the splint allows gravity to do its work, and within a few days or

- even hours some change in the angle has occurred. If the
patient is now able to abduct the arm to the original position,
the splint may be left off still longer. If not, it should be again
applied. So too, in the case of the elbow fixed in the position
of flexion. Removal of the splint allows the forearm to be
extended with the least degree of traumatization. For the
knee which has been fixed in the extended position, I allow

Fig. 61.—Roentgenogram of the wrist shown in Fig. 60 three months after
arthroplasty. 90° flexion and extension; 10° abduction and adduction.
Almost the full range of pro- and supination.

gravity to do its beneficent work by applying a little splint
while the patient is lying in bed, so constructed as to support
the thigh but to leave the calf unsupported. The weight of the
calf gradually causes a flexion of the knee. As in the case of
the shoulder and elbow, the power of the patient to resume the
original position should be tested frequently, and failure on his
part constitutes for the time being a contraindication to the
continuance of the mobilizing process.

Another effective method in the mobilization of joints is the application of a steady, gentle corrective force. This principle, frequently applied by the orthopedist, in overcoming early deformities of tubercular coxitis and gonitis, has been rendered feasible for military surgery by a number of devices. Of these the simplest are, I believe, those of Schede. Fig. 56 illustrates the splints used. Each one is so constructed as to be a flexor as well as extensor of the joint. They are easily

Fig. 62.—Arthroplasty of the metacarpophalangeal joint of the middle finger for ankylosis due to gunshot injury. *a*, The finger extended. *b*, The finger flexed.

applied by the patient himself, who regulates the degree of force by tightening or loosening the cord which approximates the arms of the lever.

When by these methods some slight degree of motion has been secured, the patients begin appropriate work in one of the shops connected with the hospital. Thus, the man with an injury to the shoulder is allowed to hammer, at first for a short time only, and if the first effort results in an inflammatory reaction the arm is again immobilized for a time. If none

occurs, the working hours are gradually lengthened and the type of work made more energetic.

Lesions of the wrist and finger joints are given this form of exercise treatment in the bookbindery or in the clay modelling department, or in the school for typewriting. The patient suffering with injury to the knee or to the ankle is placed at the
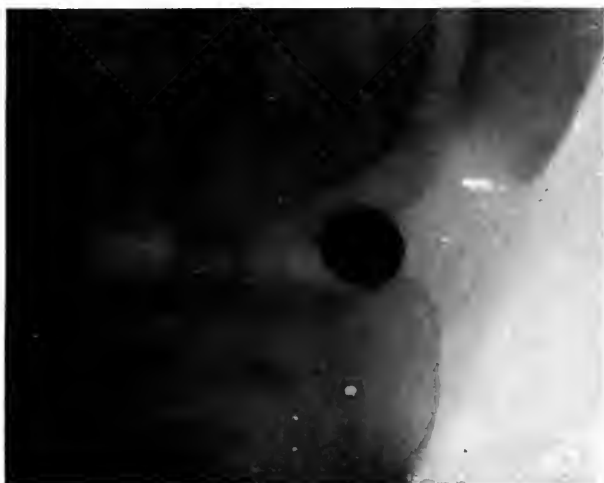
FIG. 63.—Roentgenogram of shrapnel bullet in the knee joint. The anteroposterior view showed the bullet directly in line with the tuberosity of the tibia. There was no indication for operative removal, since the function of the joint was in no way disturbed.

turning lathe in the mechanic's shop or at the sewing machine in the tailoring department. Some appropriate work can be found for almost every type of injury.

In addition, careful massage of the extremity combined with warm baths and baking, helps restore the strength of the muscles and may add somewhat to the mobility of the affected joint.

The athletic field and the farm are also of great assistance. Great care must, however, be employed in adapting the exercise to the particular requirements of the patient, since much harm can be done by injudicious treatment.

The Zander machines and other pendulum devices frequently used in mechano-therapeutic institutions, do not, in my opinion, accomplish their purpose, and are for the patient as well as the physician a most irksome mental and physical strain.

Ankylosis.—When ankylosis has occurred, and no improvement whatever is noted by the means already suggested, the question of operative interference confronts the surgeon.   In deciding for or against operation, the following factors play an
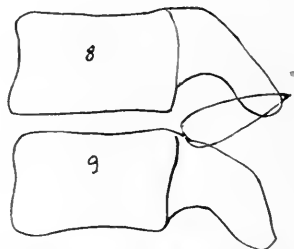
FIG. 64.—Infantry bullet lodged between the articular processes of the eighth and ninth dorsal vertebræ.   The severe pain produced by the bullet was completely relieved by extracting it.

important rôle: (1) Has the joint been immobilized in such a position as to give the patient a useful limb?   (2) What is the social condition of the patient?   Thus, for a professional flute-player who must take his seat daily in the orchestra, the criteria are altogether different than in the case of the blacksmith who must have an absolutely firm limb to stand on. (3) Which joint is involved?   Thus in the case of the knee, it would be distinctly advantageous for the flute-player to have an arthroplasty performed, whereas for the blacksmith the operation would be contraindicated.

In deciding upon the type of operation, the surgeon should be guided by a consideration of these three factors.   If the position of the joint is unsatisfactory and if, at the same time, there is no indication for mobilizing it, a juxta-articular osteotomy should be performed to correct the position of the limb. Thus, for flexion of the knee, the supra-condylar osteotomy can be used to secure extension; or, if the ankle be ankylosed

FIG. 65.—Roentgenogram of elbow in which the shrapnel splinter had been lodged between humerus and ulna. Extraction under local anesthesia by posterior incision along the lateral margin of the olecranon process.

FIG. 66.—Photograph illustrating the range of motion subsequent to extraction of the shell splinter shown in Fig. 65.

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in equinus, a wedge can be removed from the astragalus and
the foot forced into the right-angled position.

If motion at the joint is necessary for the patient's happi-
ness and efficiency, I strongly favor performing an arthro-
plasty, even in those cases where the joint destruction has
been most extensive. The results are particularly good for
the jaw, elbow, wrist, and hip (see Figs. 58, 59, 60, 61, and
62). In three or four cases in which I attempted the oper-
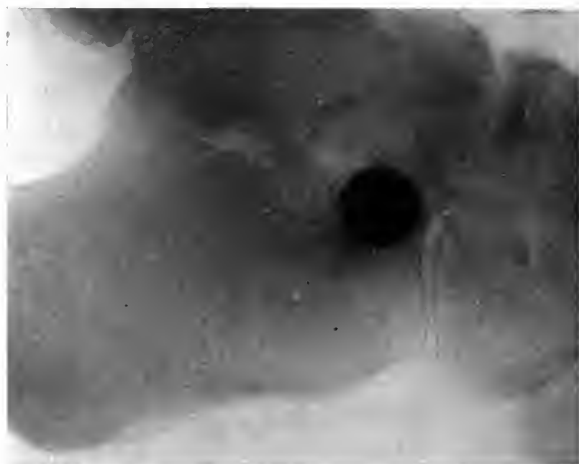
Fig. 67.—Roentgenogram of shrapnel bullet lodged in the calcaneo-
astragaloid joint. The bullet caused no pain or limitation of motion but
produced a chonic purulent discharge which was cured by its extraction.

ation at the knee and the ankle, the results gave a moderate
degree of motion and the patients were able to walk with com-
fort, although a splint was in each case necessary to prevent
undue strain upon the operated joint.

In the operative technic, I employ longitudinal incisions
wherever feasible, free the bone ends with mallet and chisel,
remodel them so as to reconstruct a joint which is mechanically
as much like the normal anatomical structure as possible,
and cover the articular surfaces either with a strip of fascia
lata and fat transplanted from the patient's thigh, or, in

certain instances, by a pedunculated flap taken from the neighborhood of the affected joint. Since my technic does not differ in any important principle from that advocated by
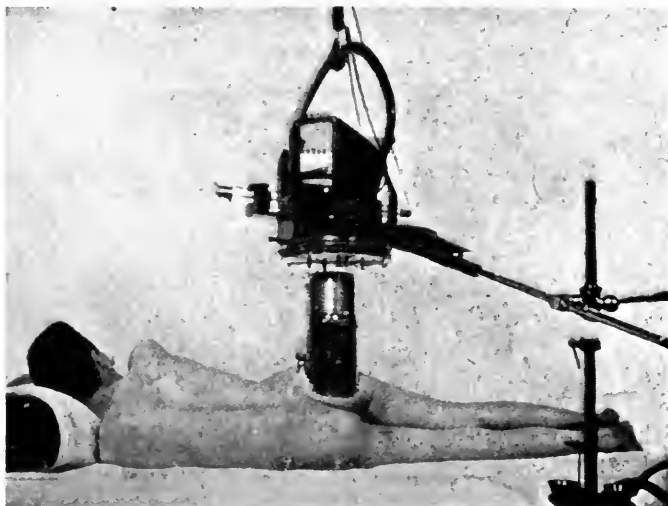
Fig. 68.—The technic of a lateral roentgenogram of the left hip. (*Method of Lilienfeld.*)
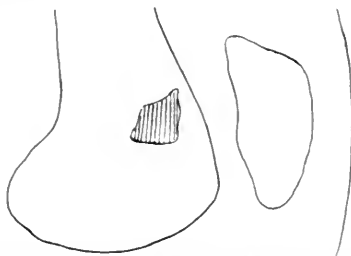
Fig. 69.—Tracing of roentgenogram showing shell splinter lodged in the femur after traversing the quadriceps bursa. For technic of removal see page 103.

Murphy, Payr, and others who have had extensive experience, I shall not go into detailed account of the operation.

In those instances where limitation of motion is due to a

single bony spur projecting into the joint, excellent results are obtained by the operative removal of this abnormality.

Foreign bodies in or near the joint deserve special consideration, since they are of peculiar interest from the standpoint of operative indications, the technic of their localization, and the method of extraction.   When a foreign body gives no symptoms whatever, there is no justification for its removal. Strange though it may seem, there is sometimes surprisingly

Fig. 70.—Photograph of the right leg of patient whose roentgenogram is shown in Fig. 69 two months after extraction of the shell splinter.   The two exposures were made on the same photographic plate, so as to illustrate the range of flexion and extension.

little interference with the normal joint mechanism, even when a foreign body of considerable size lies directly in the joint. Fig. 63 shows a shrapnel bullet lodged in the knee-joint; the patient in question had no symptoms whatever referable to the injury, and was discharged to his regiment fit for service in the field.

The indications for removal are: (1) pain; (2) interference with function; (3) the presence of a persistent sinus.   These three indications may in some instances all be present, but

any one of them necessitates removal of the foreign body. Fig. 64 shows an infantry bullet lodged between the transverse processes of the 8th and 9th dorsal vertebræ. The only symptom caused by the bullet was pain on motion of the spine. This was relieved entirely by removal of the bullet. In this instance there was little interference with the motion of the spine, but in Fig. 65 is an illustration of almost complete

Fig. 71.—Shrapnel bullet lodged in the upper portion of the tibia after traversing the knee joint. For the technic of extraction see page 104.

ankylosis of the joint due to a fragment of shell lodged in the elbow. Under local anæsthesia, working from a posterior incision, the joint was opened, the fragment removed, and almost the normal range of mobility restored to the joint (see Fig. 66). Fig. 67 illustrates a case in which there was neither pain not interference with motion although the shrapnel bullet was embedded in the calcaneo-astragaloid joint. The sole indication for removal was a purulent discharge which ceased with the extraction of the foreign body.

The technic of localization of these foreign bodies has been

discussed in such detail in treatises dealing with Roentgen-
ology that I wish to emphasize only one detail which has been
of much value to me.   All the roentgenographic methods of
determining the depth of the fragment help somewhat in local-
izing it exactly, yet they are, I find, of less practical value

Fig. 72.—Roentgenogram of a shrapnel splinter lodged in the hip joint.
Lateral view.   For the technic of removal see page 104.

than accurate exposures of the joint in question made directly
at right angles to one another.   By this simple test, combined
with careful study of the corresponding bony points, the
position of the foreign body with reference to the bone can be
more clearly grasped than by the statement that it lies so and
and so many centimeters from the skin, measured from one
point, and so and so many centimeters measured from another.
For some joints it is difficult to secure the lateral exposure.

This applies particularly to the hip, yet I have been able to secure excellent results by the method illustrated in Fig. 68 as advocated by Lilienfeld.

In removing these foreign bodies, each case must be individualized, since it seldom happens that exactly the same

FIG. 73.—Roentgenogram of infantry bullet lodged in the calcaneo-astragaloid articulation just anterior to the interosseous ligament. For method of extraction see page 105.

incision can be employed for two successive cases. The essential is to disturb the joint as little as possible by the traumatism of the operation. A few instances will illustrate some of the methods followed.

In Fig. 69 is shown a shell splinter embedded in the femur, at the level of the quadriceps bursa, which had been opened up by the bullet in its course. The operative incision was planned so as to leave the bursa (which is really a part of the

joint) intact; it was therefore made directly over the lateral
aspect of the bone, which was then chiselled open, the bullet
extracted, and the small bony canal packed.   Fig. 70 shows
the range of motion resulting.

In another instance, the projectile was lodged in the tibia.
(see Fig. 71).   The track of the bullet ran through the condyle
of the femur downward through the outer angle of the joint
into the tibia.   As in the first case, the track of the bullet was
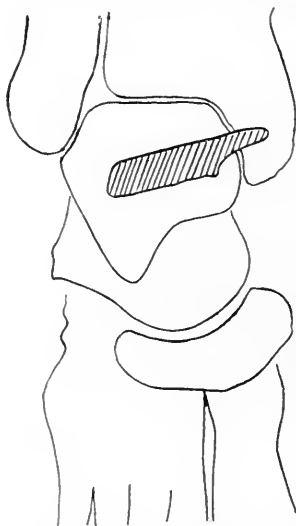
Fig. 74.—Tracing of roentgenogram of infantry projectile in the astragalus
with the tip projecting through the ankle joint into the internal malleolus.
For technic of extraction see page 105.

not followed, but through a small incision the tibia was chis-
elled open at the level of the projectile.   Here the resulting
motion was not as satisfactory as in the preceding case because
of the extensive injury to the cartilaginous surfaces of the bone.

In the case of the hip, the incision depends entirely upon the
position of the foreign body.   In Fig. 72 is shown a shell
fragment lodged near the lesser trochanter.   Here the most
advantageous incision was the anterior, running along the
outer border of the sartorius, retracting the nerve, and the

great vessels inward, until the tendon of the ilio-psoas could be identified at its insertion into the lesser trochanter. By means of long narrow retractors, the joint capsule was exposed at this point, incised, and the fragment found after some little search.

The next two cases show methods applicable to foreign bodies in the ankle-joint. In the first, the projectile lay in the calcaneo-astragaloid joint, just anterior to the strong interosseous ligament (see Fig. 73). On first view, it would seem advisable to employ an incision just below the internal malleolus; yet this would have involved considerable traumatism to the tendons which have their course in this situation. I therefore used a posterior incision, dividing the Achilles tendon at

Fig. 75.—Photograph (two exposures on one plate) illustrating the range of flexion and extension of the foot subsequent to removal of the projectile shown in Fig. 74.

the level of the calcaneo-astragaloid joint. The two bones were held apart by appropriately shaped blunt retractors, and the bullet easily extracted from the joint. The capsule and the divided Achilles tendon were united by interrupted chromic gut sutures and the leg immobilized for three weeks. Normal function both of the tendon and of the joint resulted. In the second case, the bullet was lodged in the astragalus, with its tip projecting through the joint into the inner malleolus (see Fig. 74). A horse-shoe shaped incision over the internal malleolus permitted its division just where it joins the lower extremity of the tibia. It was then turned upward like a trapdoor, the bullet removed, and the malleolus sutured in place.

The resulting motion, as shown in Fig. 75, was practically normal.

Atypical Joint Operations.—Complicated injuries to joints frequently call for atypical operations, as in the instance illustrated in Fig. 76, an extensive injury to the shoulder in which

Fig. 76.—Extensive injury to the shoulder with fracture and downward displacement of the tip of the acromion and of the clavicle. The fragments were wired in place and the arm fixed in abduction. A useful shoulder resulted which enabled the patient to continue his military service.

the tip of the acromion and part of the clavicle were displaced downward. The fractured parts were wired in position and the arm placed in abduction. At a later operation a bony spur of the humerus was removed with a resultant useful shoulder which enabled the patient to continue his military service.

CHAPTER VII

CONTRACTURES

Were the conditions for treatment of gunshot injuries ideal, and were all surgeons experienced in this type of work, contractures would seldom occur. The conditions, however, are seldom ideal, and all too frequently the medical attendant does not realize the importance of proper postural treatment and of early mobilization. Therefore, contractures are frequent in the patients referred to the base hospital.

The most common are the following:

1. *Contracture of the pectoralis major,* binding the arm to the side of the body. This occurs in almost all wounds of the axilla where the abduction treatment has not been followed. When seen at an early stage before too much scar tissue has developed, the arm can be abducted under anæsthesia, and must of course be kept in that position until all tendency to contracture has disappeared. In the later cases, this bloodless method is, however, impossible, and a tenotomy must be done; if possible, subcutaneously, or if division of the lower portion of the tendon, accessible by the subcutaneous method, does not sufficiently free the arm, a longitudinal incision must be made over the insertion of the tendon, as in the treatment of birth palsy contracture, advocated by Sever, and the entire tendon divided at this point.

2. *Flexion Contracture of the Elbow-joint.*—This is usually due to injuries of the biceps and brachialis anticus. As in the first case, the contracture can be cured, when not of too long standing, by stretching under anæsthesia. If this does not succeed, the tendons should be divided and the arm placed for a time in the extended position.

3. *Flexion Contracture of the Fingers and Wrist.*—This corresponds to the type frequently seen after an ischæmic gangrene. The method of Sir Robert Jones gives brilliant

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results in many cases. The wrist is flexed a few degrees
beyond the customary position, thus allowing some extension
of the fingers, which are then fixed in this position.   Gradually,
from day to day, with the fingers thus extended, the wrist is
extended by a suitable splint until a normal position is secured.
In other cases, the Schede splint (see Fig. 77) or corrective
plaster dressings are effective.   In other instances, however,
these methods are not applicable, owing to the density of the
scar tissue.   This is particularly true of the adduction con-
tractures of the thumb.   Operation is necessary.   A trans-
verse incision is made through the scar tissue, thus liberating

FIG. 77.—Flexion contracture of the fourth and fifth fingers due to gunshot
injury of the flexor muscles. *a*, When brought to the base hospital. *b*,
Three weeks later subsequent to treatment by means of the Schede finger
splint.

the thumb.   After abducting it, the resultant skin defect is
covered by pedunculated flaps from the dorsum of the hand.
Similar operations can be devised for contractures of the other
fingers.

4. *Adduction and Flexion Contracture of the Hip.*—It is
seldom possible to overcome this except by division of the
shortened muscles.   The adductors are divided by a 2-inch
incision over their insertion, the flexors by a longitudinal
incision near the anterior-superior spine.   The Soutter
method of subperiosteal downward displacement of the flexors
gives good results.

5. *Flexion Contracture of the Knee.*—Here, too, operative
methods are usually necessary, although in some instances,
even of long standing, the Schede splint or the genuclast will

FIG. 78.—Plaster splint for injuries in the neighborhood of the wrist holding the hand in hyperextended position. In this instance complicating injuries to the hand produced an adduction spasm of the fingers, which were held apart by means of straps passing through slits in the plaster splint.

FIG. 79.—Dorsal view of the splint shown in Fig. 78, illustrating the manner of holding the fingers apart when there is a tendency to adduction contracture.

stretch the shortened muscles. When operation is necessary, the biceps tendon should be lengthened by an open incision so as to avoid injury to the external popliteal nerve; the semitendinosus and gracilis, subcutaneously. Only in rare instances is it necessary to divide the semi-membranosus; to do this, an open incision is necessary.

6. *Equinus position of the foot,* due to contracture of the gastrocnemius and soleus, is seldom open to correction by bloodless methods. I favor the subcutaneous tenotomy in all cases where the surgeon is convinced he is dealing with a normal muscle. If there is any evidence pointing to spasticity, or if through the reflex action of any irritant the muscle might be abnormally stimulated to contraction (as by the presence of foreign bodies within its substance), the subcutaneous method is to be replaced by a plastic operation. In my hands, two methods have given equally good results: *first,* the double L-shaped lengthening; *second,* the suture method of Jones. In performing the first, the tendon is exposed by a longitudinal incision 2 to 3 inches long, depending upon the degree of shortening. The tendon is slit longitudinally in the midline with a very sharp narrow-bladed knife, and divided transversely on opposite halves at each end of the longitudinal incision. After correcting the equinus deformity, the two halves, which should overlap at least 1 inch are sutured together with several interrupted chromic gut stitches. In the Jones method, a 1-inch longitudinal incision exposes the tendon which is lifted from the subjacent tissues by a blunt instrument (periosteal elevator). Two strong sutures are taken in the tendon about $\frac{1}{2}$ inch from one another, the tendon is divided transversely between the sutures and after correcting the equinus, the ends of the sutures are knotted, so as to prevent retraction of the tendon ends. Care must be taken not to apply a pressure pad to the gap between the tendon ends, since this would prevent its regeneration. The same precaution must be exercised after the subcutaneous tenotomy.

7. *Torticollis.*—This and the following are rare types of contracture in military work. Torticollis results from an injury to the neck which has not been splinted in the proper position (see p. 54). When once developed, it can seldom

be corrected except by division of the sternocleido mastoid. Contrary to the usual conception, this can in most cases be safely performed by the subcutaneous method. Only when
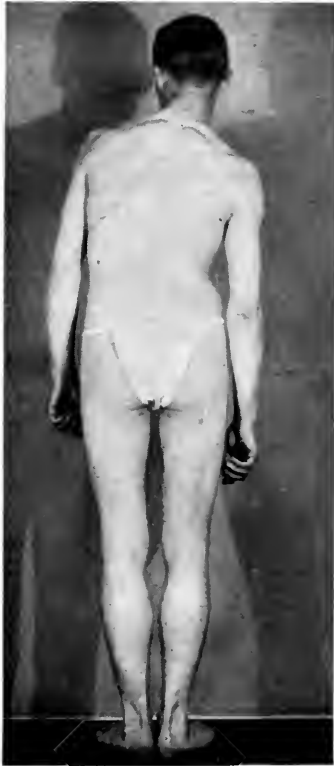
FIG. 80.—Elevation of the left shouder with subsequent secondary scoliosis due to gunshot injury in the neighborhood of the left trapezius muscle. Treatment by the "Abbott" method unavailing until supplemented by open incision of the contracted muscular fibers.

the contracture is very marked, involving division of the deep cervical fascia, do I find it necessary to make an incision.

8. *Scoliosis.*—I have seen only two instances as the result of gunshot injuries. In both, the injury occurred to the

shoulder muscles, the shoulder was drawn upward as a consequence, and a convexity of the spine toward the side of the injury developed in the upper dorsal region (see Fig. 80). Correction by the Abbott method, which would seem to be particularly applicable to cases of this type, gave only fair

FIG. 81.—Illustration of the type of splint applicable to injuries of the left cerebral cortex or pyramidal tract, producing a spastic paralysis of the right arm and hand.   The splint overcomes the pronator spasm of the forearm muscles and the flexion contracture of the hand and fingers.

results.   In the one case, I secured a complete cure by open division of the fibres of the trapezius, which were drawing the scapula upward, followed by correction in the Abbott frame and immobilization in plaster.

9. *Contractures subsequent to lesions of the Rolandic area or of the pyramidal tract.*   These injuries result in a spastic paralysis in which the adductors, flexors and pronators overcome

the antagonistic weaker muscles. A splint should of course be applied to prevent a formation of contractures. Fig. 81 illustrates a simple apparatus which overcomes the tendency to flexion at the elbow and hand and keeps the forearm supinated. For the lower extremity an abduction frame with a device to prevent toe-drop is indicated.

The Orthopedic Treatment of Burns.—The prevention of contractures subsequent to extensive burns in the neighborhood of joints, constitutes an important and difficult phase of orthopedic work. If the limb be immobilized in the flexed position, a flexion contracture is bound to occur, whereas the extended position increases the area denuded of skin, rendering the problem of wound healing more difficult, and at the same time creates the danger of a joint stiffened in the extended position. The essential in the treatment, therefore, is constant change in the position of the limb so far as this is compatible with effective treatment of the wound. A specific example will make the method clear. Assume that the patient has an extensive burn over the front of the elbow. A splint is applied holding the forearm at an angle of about 145°. This is kept on until the sloughs have disappeared and the wound has begun to granulate. From this time on two splints are used. One holding the arm flexed to about 90°, the second extended to 170°. These are changed on alternate days. As the wound epithelializes the patient is allowed to change the splints himself every few hours and is encouraged to exercise the flexors and extensors of the joint. This motion causes some delay in the healing of the wound but has the great advantage that it maintains the function of the part.

8

CHAPTER VIII

THE TREATMENT OF NERVE INJURIES

The types of splint applicable to nerve injuries have already been described (see p. 50), as well as the symptoms by means of which a nerve lesion can be recognized. When the patient reaches the base hospital the splint applied at the front should be kept on, or, in case this postural treatment has been neglected, it should be instituted at once. In addition, every measure should be taken to keep the paralyzed muscles in condition of maximal tone by massage and electrical stimulation. Galvanic, faradic, and high frequency currents can all be applied with excellent effect. This portion of the work should be controlled by an experienced technician. The custom of turning over this branch of therapy to a half-trained assistant cannot be too strongly condemned. Electro-therapy in particular requires the most careful anatomical and technical training if it is to be anything except a therapeutic placebo.

Primary nerve suture is seldom possible after a gunshot injury, since in almost all instances of extensive laceration the danger of infection constitutes a contraindication. As soon, however, as the primary reaction has subsided and the infection has been controlled, *the surgeon stands before the question of whether to operate or to wait for the spontaneous return of function in the injured nerve*. On this subject there is the greatest difference of opinion among men of experience. Some maintain that the operation should be performed as soon as the operative field is reasonably aseptic; others claim that by postponing the operation five or six months a great proportion of the nerve injuries recover without operative interference. I shall state a few practical rules of guidance which have stood me in good stead:

1. When the symptoms of a nerve lesion are progressive, operate at once. Thus, for instance, a patient brought to me three days after the injury complained of slight tingling

in the area supplied by the right median nerve, and there was a slight weakness of the flexors of the fingers.   On the following day, the tingling had become a slight steady pain.   By the end of the fifth day, the patient was suffering agonies.   It was evident that some progressive lesion was present—either a scar tissue formation enclosing the nerve or a rapidly growing intraneural tumor.   At the operation, a hæmatoma the size of a small chestnut was found within the nerve, and upon its enucleation the pain at once subsided.

2. If the symptoms are regressive, do not operate.   Thus, it not infrequently occurs that when a patient is brought into the hospital there is a complete paralysis of the muscles supplied by the musculospiral.   Three weeks later, when the wound is healed and the muscles are tested after removing the splint which has kept the hand constantly in the hyperextended positions, a faint flicker of movement may be discernible in the muscles previously completely paralyzed. In this case, the prognosis is excellent without operative interference, since the nerve has probably been slightly traumatized by pressure or blood extravasation and has not suffered a severance of its continuity.

3. In other cases, where there is no change whatever in the extent of the paralysis or of the sensory symptoms, wait until the wound has healed, and then determine on the basis of the anatomical course of the nerve and the direction of the bullet whether there is a strong probability that the nerve was directly injured by the passage of the projectile.   If so, operate; if not, wait still longer.   This rule requires the most accurate anatomical knowledge and a good eye.   If observed with care, it will seldom lead the surgeon into error.

The electrical tests are, in my experience, of little or no value in deciding whether operation is indicated.   It frequently occurred that in cases, in which all the muscles showed a typical reaction of degeneration, and operation was advised by the electro-diagnostician, perfect recovery occurred without operative interference.   Whereas in other instances, in which the electrical reactions were such as to lead an expert to advise conservative treatment, operation showed a complete division of the nerve.

The great advantage gained by performing operation at an early date is made evident by the **pathological conditions** which confront one after gunshot injuries to the nerves.   Two types of injury have already been mentioned—(1) a traumatism of the nerve, due to the passage of the bullet in its immediate neighborhood, without severance of any nerve fibres; (2) the presence of a small hæmatoma within the nerve.

a   b

FIG. 82.—Injury due to downward path of projectile which grazed the angle of the jaw. a, The small flesh wound. b, The right facial paralysis, evidenced by inability to raise the angle of the mouth, due to concussion of the facial nerve.   The paralysis disappeared one week subsequent to injury.

A number of other pathological possibilities may be present: (1) There may be a concussion of the nerve, without any evidence of traumatism.   Thus, in Fig. 82 is shown the photograph of a patient who gave all evidences of a facial paralysis, although there was no wound in the immediate neighborhood of the nerve.   The paralysis subsided after five days—a sure indication that no real traumatism of the nerve could have occurred.   (2) The nerve may be partly divided by the bullet. At the point of injury, scar tissue develops, producing a small

hard nodule, which may lie either toward the periphery of the nerve or near its centre, depending upon the exact site of the laceration. (3) In other instances, the nerve is completely divided by the projectile. In some cases the nerve ends remain in contact and are rapidly united by scar tissue, which may be minimal in amount or may be sufficiently great to completely obstruct the downward growth of the axis cylinder processes. In still other cases (and this is, according to my experience, the rule) the nerve ends are forced apart by the projectile and lie separated from one another, so that the continuity of the nerve is completely interrupted. The nerve ends become rapidly embedded in scar tissue, and their ends show the fibrous enlargement typical of the divided nerve, which is unable to regenerate. It is clear that the longer the operation is postponed in such cases, the greater will be the development of scar tissue and the more extensive the degeneration of the nerve, both ascending and descending. (5) In addition to a hæmatoma within the nerve, there may also be small particles of lead, clothing, etc., within its substance which usually cause intense pain although seldom complete paralysis.

The operative treatment of nerve injuries depends upon a knowledge of the physiological processes involved in nerve regeneration. Whatever differences there may be in the present attitude of physiologists and neurologists toward this question—whether the regeneration is due entirely to the downward growth of the axis cylinder processes from the proximal stump into the distal, or whether the opposing school is correct in its contention that the sheath of Schwann of the distal stump contributes to the regeneration—one fact is admitted by all: that the conditions for regeneration are most favorable when there is an intimate union between the axis cylinder processes of the divided nerve ends. Upon this fact the operative treatment is based. In all instances, the operator must try to secure this intimate union between the axones whose continuity has been interrupted by the projectile.

The exact method applicable to the case depends upon the nature of the pathological process which is found at the operation.

1. *If the nerve is seen to be merely traumatized* or pressed upon by a bone fragment or scar tissue, nothing should be

done except remove the external cause of the pressure.   Should
this be due to scar tissue, some means must be taken to prevent
its recurrence.   This is best done by changing the position of
the nerve from the area where scar tissue is likely to develop
into one where it is surrounded by normal healthy muscles.
As a rule this is readily accomplished by suturing the muscles
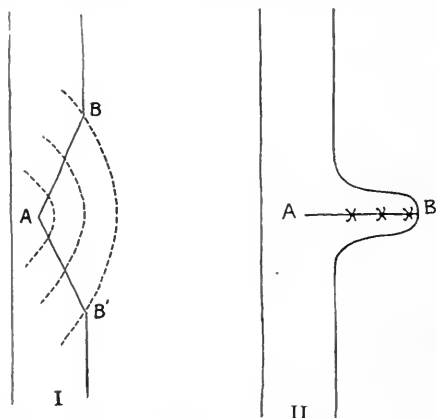
Fig. 83.—Method of nerve suture after excision of scar tissue invading a
portion of the nerve.   Fig. I.—BAB', The line of excision of the neuroma.
The sutures (dotted lines) pass through the perineurium.   When drawn taut,
as shown in Fig. II, B is approximated to B', producing a little projection of
the nerve.   Prognosis in these cases is good because of the accurate approxi-
mation obtained by this method.

which normally are superficial to the nerve in such a fashion
as to bring them deep to the nerve—that is, interpose them
between it and the scar tissue.   If this is impossible—as, for
instance, in the case of the external popliteal nerve, where it
rounds the head of the fibula—the nerve should be ensheathed
in fascia, its smooth inner surface turned inward, or in a tube
of calf's artery hardened in alcohol (see footnote).

[1] The method of preparing the artery is as follows: Arteries of varying
size are mounted on glass tubes of appropriate diameter and hardened
in 10 per cent. formalin for three days.   They are then thoroughly
washed in running water, boiled for half an hour and kept in 90 per cent.
alcohol.   At a secondary operation, two months subsequent to the
implanting of such an artery, I found its intima still smooth and the nerve
absolutely free from adhesions.

2. *If a small nodule of scar tissue* is felt within the nerve, indicating its partial division by the projectile, this area should be excised and the corresponding axis cylinder processes united by fine perineural stitches (see Fig. 83). In these cases the prognosis is particularly good, since it is easy to secure accurate apposition (see Fig. 84).

3. *If scar tissue is generally present* throughout the nerve, two courses are open, dependent upon its degree of development. If a small quantity is present, then by careful dissec-

Fig. 84.—Photographs (two exposures on one plate) illustrating the effect of nerve suture by the method shown in Fig. 83 eight weeks subsequent to the operation.

tion this can be removed from within the substance of the nerve without disturbing the continuity of the nerve bundles. This operation is known as internal neurolysis. If, however, an extensive scar tissue formation is present, completely interrupting the course of the axones, the area must be entirely excised and a suture of the nerve performed.

4. *When a nerve has been completely divided*, there is nothing to be done except *nerve suture*. In performing this delicate operation, no surgeon at the present day has a right to urge his method authoritatively, since the present status of nerve suture is an uncertain one. We do not know whether the perineural stitch advocated by most men is preferable to the

transneural stitch advocated by such authorities as Wilms and Sherren; also there is an excellent possibility that some other method of nerve suture may be introduced superior to either of these.   Certain it is that the results of nerve suture by our present methods are none too good.   Under all cir- cumstances, sufficient of the injured nerve must be excised to render healthy axis-cylinder processes visible.   The cross- section of the healthy nerve is quite characteristic; the indi- vidual nerve bundles stand out as white, sharply circumscribed areas, separated by intervening bands of connective tissue containing the nutrient vessels.   The hæmorrhage from the proximal stump is profuse, and should be controlled in the case of a large nerve by ligature of the spurting vessel; in the case of the smaller nerves, by the application of pledgets of adrenalin.   A suture should not be attempted until the hæmor- rhage has been controlled, since the presence of a hæmatoma between the nerve ends endangers the success of the operation.

Excision of the nerve to this extent frequently renders it difficult to unite the two ends. Flexion of the limb may help to bridge the gap; in the case of the median nerve, 2 inches can readily be overcome; in the case of the sciatic, $3\frac{1}{2}$ or even 4 inches. Traction can also be exerted on the nerve stumps without much danger, although no great force should be applied to the proximal stump, since according to Warrington, too much tension produces a degeneration of the anterior horn cells. To assist in approximating the stumps, it is advisable to place traction sutures about $\frac{1}{4}$ inch from the cut surface of the nerve. These are best inserted before the scar tissue has been excised, so that the healthy cross- section of the nerve should be exposed to the air as short a time as possible. They are inserted by taking two longi- tudinal bites of perineurium (see Fig. 85), two in each of the nerve stumps, so placed that when an assistant grasps the two attached to the proximal and a second assistant grasps the two attached to the distal, traction upon them will bring the nerve ends in apposition. The perineural stitch which I myself have usually employed is illustrated in Fig. 85. Very fine silk is used; the needle passes in about $\frac{1}{16}$ inch from the cut perineural surface, emerges between the perineurium and the

nerve trunk, passes into the other stump at this same plane,
and emerges again $\frac{1}{16}$ inch from the cut edge. The suture is
tied at once and if properly inserted should produce no in-
version of the perineurium but a very slight eversion. As
few sutures as possible should be inserted, consistent with an
accurate approximation of the perineurium on all sides. It
must be remembered that the more stitches inserted the greater
the danger of scar tissue formation. Particular care must be
exercised not to tear the nerve fibres. If the nerve is once
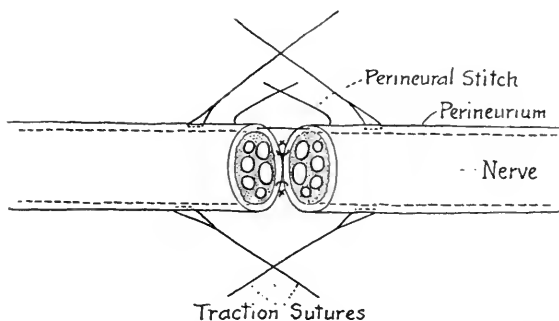
Fig. 85.—The perineural method of nerve suture for complete division of
a nerve. The two perineural stitches on the deep surface of the nerve have
already been drawn tight. One suture above has been inserted and two
others would be required to secure approximation. Note the four traction
sutures passing through the perineurium about $\frac{1}{4}$ inch from the cut surface.

lacerated by unfortunate handling, it is practically impossible
to insert a successful suture. When the perineural stitches
have been inserted (usually three or four for the median or
musculospiral, six to eight for the sciatic), the traction sutures
are removed.

The transneural stitch differs radically from the peri-
neural one, in that the needle is carried directly through the
entire thickness of the nerve without regard to the nerve
bundles. Its advocates claim comparatively little trauma-
tization of the nerve paths and the great advantage of more
accurate apposition. Certain it is that the perineural stitch
does not give absolute approximation, since the nerve fibres
within the perineurium retract a little when the nerve is

subjected to marked tension, and thus a small intraneural gap is left even when an external view shows perfect approximation of the perineurium. In the case of a large nerve such as the sciatic, it is, I think, advisable to combine the perineural stitch with the transneural so as to overcome this gap between the nerve ends.

In instances where it is impossible to approximate the nerve ends because of extensive loss of substance, some bridging method must be followed. Here, too, no one dares speak with the voice of authority. I can only state my own personal experience
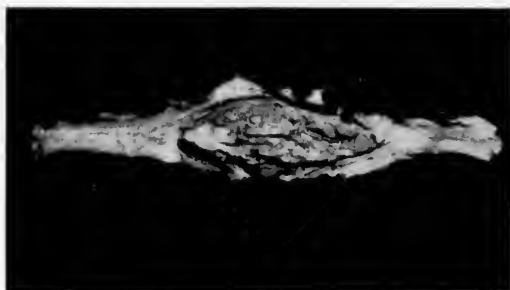
Fig. 86.—Specimen from sciatic nerve of dog removed at autopsy 12 weeks after implanting the nerve ends into a calf's artery filled with agar-agar. (*Edinger's method.*) The photograph illustrates the failure of the two ends to unite.

with methods of this kind. First, as to the technic proposed by Edinger, namely, the insertion of a tube of agar-agar between the divided nerve ends. Despite the excellent theoretic basis for this method, it gives poor results both in the animal experiments in which I tried it (see Fig. 86) and in those operations on human beings performed by other surgeons which I have had occasion to examine. The method of investing the nerve ends in a fascial sheath, as followed by Dean Lewis of Chicago, has not, so far as I know, been given sufficient trial in human beings to justify it as a sound procedure, although its brilliant success in animals would argue in its favor. It must be emphasized, on the other hand, that the possibility of nerve regeneration in dogs is much greater than in human beings. Thus, for instance, it is the rule when the anterior

crural nerve of a dog is divided that union occurs within a comparatively short time, even without nerve suture; whereas in human beings such spontaneous cure, so far as I know, seldom occurs.

The method which I have followed is based upon the physiological fact that the essential factor in nerve regeneration is an intimate union of the axones of the proximal stump with those of the distal. That the latter are degenerated does not seem to be of significance. I have therefore transplanted seg-
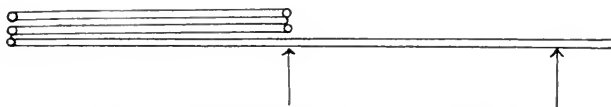
Fig. 87a.—Diagram illustrating the method of bridging a gap in a nerve by a transplantation of multiple segments of a sensory nerve. Two segments of a sensory nerve have already been cut and sutured together. The arrows indicate the lines of incision for two more segments. The incisions pass through the entire thickness of the nerve but leave the perineurium on one side intact. To hold the nerves together very fine perineural sutures are inserted.
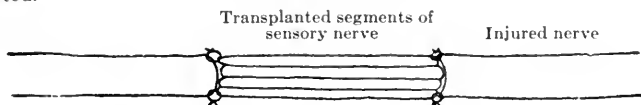
Fig. 87b.—Diagram illustrating the method of bridging a gap in a nerve by transplantation of multiple segments of a sensory nerve. The segments sutured together to form a trunk corresponding in diameter to the injured nerve are held in place by perineural stitches similar to those shown in Fig. 85.

ments of other nerves of the body to fill in the gap between the ends of the divided nerve. For this purpose it would, of course, be impossible to use a motor trunk without producing paralysis. I have therefore sacrificed sensory nerves; in the arm, the radial or internal cutaneous; in the foot, the external saphenous. Since the cross-section of these sensory nerves is seldom equal to that of the trunk which is to be bridged, it is usually necessary to construct a cable of appropriate diameter by employing multiple segments (two to eight) of the sensory nerve.

The technic is as follows: A sensory nerve is laid bare for a sufficient extent, depending upon the number of segments

which must be utilized to give a cross-section corresponding
to that of the injured nerve. It is freed from its bed, com-
pletely divided at one end, and then doubled on itself to form a
loop slightly longer than the gap to be bridged (see Fig. 87).
At the closed end of the loop, the nerve is again divided, except
on one side, where the perineurium is maintained intact. This
step of the operation requires some practice but is perfectly
feasible. Two fine perineural stitches are taken, holding the
first segment in intimate contact with the second at its upper

Fig. 88.—Result of transplanting the external saphenous nerve for a 4-inch
gap in the course of the musculospiral. The photographs were taken six
months after the operation.

and lower extremities. The nerve is then further lifted out of
its bed so that a third segment, corresponding in length to the
first two, can be measured off, and sutured to these. In a
similar way a fourth or fifth segment can be united to the pre-
ceding (see Fig. 87a). For this, Kirby silk and the finest
needles, such as those used in arterial sutures, should be em-
ployed. The nerve cable thus constructed is implanted into
the gap between the ends of the divided nerve and held in
place by the typical perineural suture (see Fig. 87b). I have

had excellent success by this procedure.   Fig. 88 illustrates a case of musculospiral paralysis in which 4 inches of the nerve were completely shot away, and in which the gap was bridged by the external saphenous nerve.   Complete return of the motor power resulted five months after the operation.   In

<div style="text-align:center;">

a   *b*

</div>

Fig. 89.—Two photographs illustrating the effect of transplanting the dorsal sensory branch of the ulnar nerve to bridge a gap in the parent trunk, $1\frac{1}{2}$ years subsequent to the operation. *a*, To show the absence of atrophy of the hypothenar muscles.   *b*, The power of spreading the fingers apart and the absence of atrophy of the interossei.   There was anesthesia of the dorsum of the little finger and ulnar border of the hand but normal sensation over the palmar surface, indicating the growth of sensory fibers along the transplanted nerve.

another case of ulnar nerve paralysis, in which the dorsal branch of the ulnar nerve was used to bridge the gap, function returned eight months after the operation and the atrophy of the interossei present at the time of the operation disappeared a year and a quarter later (see Figs. 89*a* and *b*).

In all cases of nerve suture, the operator must preclude the possibility of the reformation of scar tissue about the nerve by changing its position. This can usually be accomplished by transplanting the nerve as already explained on page 118.

Whether it is advisable, in addition, to enclose the sutured nerve with fascia, cargile membrane, or hardened artery, is one of the numerous questions relative to the operative technic which awaits the answer of accurate experimental investigation.

5. *When there is intraneural* pressure, due to a hæmatoma or foreign body, the nerve should be slit longitudinally so as to cause minimal traumatization, the tumor removed, and the perineurium reunited by fine transverse stitches.

Operative Exposure of the Nerves.—Of course, in all nerve operations, the general principles of rigid asepsis and minimal

Fig. 90.—The stirrup forceps for nerve operations.

traumatization must be rigidly adhered to. Never grasp the nerve roughly with forceps; always lift it gently by the perineurium; never allow it to dry; never free it unnecessarily from the surrounding tissue. The instruments should correspond in delicacy to the nature of the work required. The finest forceps, needles and suture material should be used. The instrument shown in Fig. 90—the stirrup clamp—is of particular value in lifting the nerve from its bed; by releasing the catch, the stirrup can be opened, the nerve brought over the lower bar, and when again closed, the nerve can be held taut without danger of injuring it. The operation should be performed without the Esmarch bandage, to be sure that no postoperative hæmorrhage occurs.

As a rule, with practically no exceptions, no attempt should be made to expose the nerve at the point of injury, since it is

here embedded in scar tissue and frequently is so degenerated as to be non-recognizable. It is much simpler to expose it above and below the lesion, and then work toward this central point. To find the nerve quickly and accurately, it is necessary to have exact anatomical knowledge of the course of the nerve with especial reference to the muscular cleavage planes. The following suggestions for the operative exposure of the nerves have proven of value to my students.

Musculospiral Nerve.—This is readily found near the bend of the elbow by a longitudinal incision along the inner margin of the brachioradialis muscle (supinator longus). The incision is deepened between the supinator on one side and the brachialis anticus on the other side. The nerve is found between these two muscles. Care must be taken not to confuse it with the musculocutaneous nerve, which lies near the musculospiral at this point, although on a more superficial plane. They are readily distinguished by following the nerves upward, when the musculocutaneous is seen to emerge from between the brachialis anticus and the biceps, whereas the musculospiral passes backward.

It is difficult to locate the musculospiral in its course back of the humerus, since it is here deep under the muscles and there is no certain guide to its position. It is, however, readily found in the upper portion of its course by bluntly separating the long head of the triceps from the external head. Therefore, in injuries to the musculospiral it is well to expose it at this point and at the elbow, and follow the nerve upward and downward to the point of injury.

Of the two branches of the musculospiral nerve, *the radial and posterior interosseous*, only the former has surgical significance, since the posterior interosseous divides into numerous fine filaments at such a high point that its suture is seldom, if ever, feasible. The radial nerve can be used with great advantage for transplantation purposes, since its loss occasions little or no disturbance of sensation. It can be found by retracting the brachioradialis muscle (supinator longus) toward the radial side.

Median Nerve.—In the upper arm this nerve is easy to identify because of its immediate relation to the brachial artery.

No surgical significance attaches to the crossing of the nerve and artery, so frequently emphasized in the anatomical text-books, since the two structures are so intimately associated that the least traction with the forceps brings the nerve to the inner or to the outer side of the vessel. At the elbow, the nerve lies almost directly in the midline and is exposed by dividing the expansion of the biceps to the inner portion of the fascia (Lacertus fibrosus) when it is found passing into the arm between the two heads of the pronator radii teres. The deep head of the muscle separates the nerve from the ulnar artery. About 1 inch above the elbow, the branch to the pronator radii teres and flexor carpi radialis emerges from the parent trunk. Care should be taken not to injure it.

At the wrist, the nerve is found just to the ulnar side of the flexor carpi radialis tendon. It passes beneath the annular ligament just to the ulnar side of the flexor sublimis tendon to the index-finger.

Ulnar Nerve.—This lies about one-quarter of an inch posterior to the artery in the upper half of the arm and then passes backward to the well-known groove in the internal condyle of the humerus. Throughout most of its course it lies posterior to the fascial septum separating the anterior from the posterior groups of muscles.

For a short distance below the elbow, it is difficult to find the nerve because it is buried in the fibres of the extensor carpi ulnaris; but in the lower two-thirds of the arm it is easily discovered by using the flexor carpi ulnaris as a guide. The nerve lies just to the radial side of this muscle and its tendon. About 4 or 5 inches above the wrist, the dorsal sensory branch passes backward. It is of significance for transplantation purposes, in case it is necessary to bridge a gap between the ends of the divided nerve.

Musculocutaneous.—The emergence of this nerve between the brachialis anticus and the biceps near the bend of the elbow, has already been referred to in describing the musculospiral nerve. The upper portion of the nerve is laid bare by separating the coracobrachialis from the short head of the biceps.

Internal Cutaneous.—Like the radial, this is of significance for transplantation purposes, particularly when bridging a

gap in the ulnar or median nerves in the upper arm. Its position varies somewhat, but it is usually found between the ulnar and the median.

The Circumflex Nerve.—Operative exposure of this nerve is very seldom necessary in military surgery. The lower end of the brachial plexus has to be exposed by upward retraction of the pectoralis major and the nerve identified as it passes off the posterior trunk of the plexus.

The Brachial Plexus.—Ample operative exposure is given only by a long incision running from a point 4 inches above the clavicle to the axilla. The clavicle is divided by a Gigli
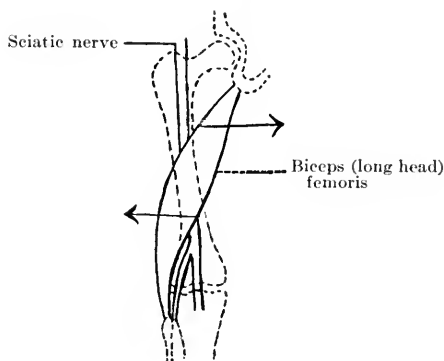
Fig. 91.—Diagram illustrating the relation of the great sciatic nerve to the long head of the biceps femoris muscle. To expose the nerve in the upper third of the thigh, the outer border of the muscle is found and drawn inward. In the lower half of the thigh the inner border is found and drawn outward.

saw, and the two ends are retracted. Great care must be exercised when freeing the plexus from the great vessels, and the operation should never be undertaken except by a surgeon experienced in vascular technic.

Sciatic Nerve.—When exposure near the sacro-sciatic fora-men is necessary, the best incision runs from the midline of the thigh at the lower border of the gluteus maximus over to the trochanter and upward with a sweep toward the midline near the upper border of the muscle. The skin muscle flap is retracted inward giving free exposure of the upper portion of the nerve. Some hæmorrhage is encountered in dividing

9

the fibres of the muscle near the trochanter, but much less than were the muscle divided directly in the course of the nerve.

In laying bare the sciatic in the thigh, the relation of the long head of the biceps muscle is of great importance. It is to be recalled that this portion of the muscle has its origin from the tuberosity of the ischium in common with some of the inner hamstring muscles, and that therefore its course must be a slanting one, from within outward. It crosses the nerve in the upper third of the thigh. Above this point of crossing, it should be drawn to the inner side in order to expose the nerve; below this point, it should be drawn to the outer side (see Fig. 91). Adherence to this rule will save the operator much inconvenience.

Internal Popliteal.—An incision directly in the middle line of the popliteal fossa lays the nerve bare. Like the sciatic, it is almost always embedded in a fatty envelope, even in thin individuals. It should therefore be sought where the operator sees the adipose tissue between the muscles.

The two important branches to the heads of the gastrocnemius pass off from the nerve near the upper end of the popliteal fossa, and should always be carefully identifieb, so as to avoid injury.

Posterior Tibial.—In the lower two-thirds of the leg the nerve is best exposed by an incision on the mesial aspect following the inner border of the soleus muscle and the Achilles tendon. The Achilles tendon and the muscular mass consisting of soleus and gastrocnemius are retracted outward, baring the deep layer of the fascia. When this is incised, the nerve is found lying directly beneath it. Reference to Fig. 92, a diagrammatic cross-section through the calf in the mid-third, will clarify these relations.

In the upper third of the calf, this incision cannot be employed, since the nerve lies too near the midline. It is exposed by a median incision which is deepened through the fibres of the gastrocnemius and soleus.

External Popliteal.—The tendon of the biceps serves as a guide for this nerve. The relation of the two structures is not always exactly the same, since in some individuals the

tendon overlaps the nerve, whereas in others a gap of a quarter
of an inch may separate them.

Anterior Tibial.—The nerve is found by exposing the
outer border of the tibialis anticus muscle. Near the ankle,
the extensor proprius hallucis lies on its outer side; nearer
the knee, the extensor longus digitorum. A large branch to
the tibialis anticus muscle passes off almost immediately after
the separation of the external popliteal nerve into its terminal
branches.
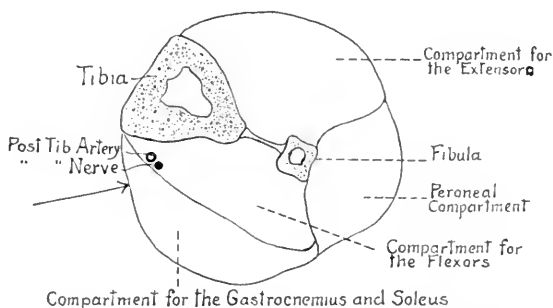
Fig. 92.—Diagrammatic cross-section of the calf in the lower half, illus-
trating the fascial compartments for the muscles and the location of the pos-
terior tibial nerve. The arrow indicates the point of incision for exposing
the nerve. The gastrocnemius and soleus are drawn toward the fibula laying
bare the deep layer of the fascia, beneath which the nerve lies.

Musculocutaneous Nerve.—This lies directly in the sub-
stance of the peroneus longus. The sensory portion emerges
from the fascia in the lower third of the calf near the septum
which separates the peroneal muscles from the anterior
extensors.

External Saphenous Nerve.—The significance of this nerve
lies in its value for transplantation purposes. It is found
directly in the midline of the calf in immediate association
with the external saphenous vein, which frequently lies directly
over the nerve hiding it from the view of the inexperienced
operator.

Postoperative Treatment.—Subsequent to the operation
the treatment as practised before should be continued; that is
the extremity should be properly splinted and the paralyzed

muscles should be given daily massage and electrical stimulation. Whenever possible the patient should be allowed to use the extremity, since in this way the circulation is best kept normal.

It is advisable to keep the patient under observation until the muscles have recovered power. If for economic, military or social reasons, it is impossible for the patient to remain in the hospital, he may be allowed to go about his work, reporting daily for the necessary treatment and for examination.

Prognosis.—Concussion and contusion of the nerve yield rapidly to non-operative treatment. Scar tissue formation external to the nerve without interruption of the continuity of the nerve fibres is easily removed and return of function should occur in approximately 100 per cent. of the cases. Endoneural scar formation on the other hand does not yield as readily to treatment. When but slightly developed, so that the internal neurolysis can be practised, the prognosis is more favorable, than in those instances where owing to extensive scar tissue development, excision of the neuroma is necessary with subsequent nerve suture. When the projectile has injured a small portion of the nerve resulting in a comparatively small scar, excision without complete division of the nerve gives excellent results in the majority of cases, because of the accuracy with which the nerve ends can be brought into apposition (see Fig. 84).

When complete nerve division has occurred, cure results, so far as I can judge from reliable statistics of other operators and from my own experience, in not more than 40 per cent. of the cases. This poor result, though partly due to the technical difficulties associated with the secondary nerve suture, undoubtedly indicates the need for careful experimental work to improve the present operative technic.

CHAPTER IX

INJURIES TO TENDONS AND TENDON OPERATIONS

The tendons most frequently injured in military practice are those of the hand and fingers. As a rule, the projectile traversing the hand splinters one of the metacarpal bones and divides one or both groups of tendons. The infantry projectile seldom does damage to the tendons of more than one finger unless its course happens to be an oblique one. Shell fragments, however, can produce much more extensive destruction. The proper immobilization of these injuries has already been discussed in Part I. When both flexors and extensors have been injured, there is little to be done except immobilization in the midposition. If either flexor or extensor has suffered an isolated injury, then the hand and fingers should be so splinted as to relax the tension upon the injured tendon and afford the maximal opportunity for contact between the tendon ends. It is rarely possible to perform a direct tendon suture, owing to the infection which usually accompanies the injury.

These injuries to tendons constitute, however, only a minor field in tendon surgery. A far wider scope is given by those paralytic conditions in which owing to the impractibility of nerve operations, tendon transplantations should be executed to restore the normal muscle balance. Since all types of tendon operations, whether they be suture for traumatic lesions, or transplantations for paralysis, are based upon the same principles, it is wise before describing the specific operations for injuries to the tendons of the hand to outline these fundamental facts.

During the winter of 1912, at the suggestion of Prof. Lange of Munich, Henze and Mayer investigated the cause of the adhesions which develop subsequent to tendon transplantations. In their work, attempt was made to prevent the de-

velopment of the adhesions by surrounding the tendon with various substances: vaseline, bismuth paste, fascia, veins, cargile membrane, thin tubes of rolled silver, etc. None of these methods gave good results; in fact, with the exception of the cargile membrane, there were more adhesions after implantation of these substances than before. The cargile membrane proved to be more favorable, yet by careful control experiments it was conclusively shown that it had no specific effect in preventing adhesions. Finally the suggestion of Biesalski was followed, and the transplanted tendon drawn through the sheath of the paralyzed. All of these sheath experiments resulted excellently; even after 4 weeks' fixation there were no adhesions to the operated tendon, but it was able to glide to and fro within the sheath with almost the normal range of motion.

This clear-cut evidence in favor of Biesalski's method, pointed the finger in the direction of a technic which would coördinate the operation with the normal gliding mechanism of the tendon. It became evident, however, as soon as this idea was followed out that the knowledge of tendon anatomy and physiology was entirely inadequate for the purposes of exact surgical work. Therefore, before an operative system could be evolved, it was necessary to study the anatomy and physiology of tendons from a new point of view. No one, neither physiologist, anatomist, nor surgeon, had as yet considered the questions of how a tendon glides, the exact function of the tendon-sheath, the relation between the sheath and the connective-tissue structures surrounding the tendon, the tension of the tendon, nor a number of other important physiological problems.

This research work was conducted by dissections on the cadaver controlled by microscopic examination, by experiments on dogs, and by observations during operations on human beings. The results of the work are published in full under the title "Die Physiologische Sehnenverpflanzung" (Springer, Berlin; Paul Hoeber, New York). The reader is also referred to three articles by the author published in "Surgery, Gynecology and Obstetrics" for February, March and April, 1916.

Anatomy of Tendons.—The easiest method of grasping the essentials of the anatomy of tendons is by study of a series of cross-sections taken through a tendon above the sheath, and at various points within the sheath. Fig. 93 represents a cross-section through the tendon of the extensor proprius hallucis, 1 inch above the intermalleolar line. It is observed
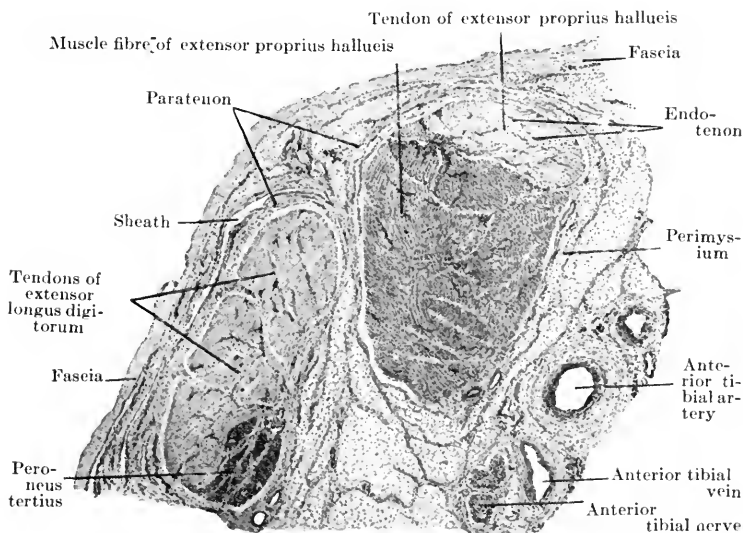
FIG. 93.—Microscopical cross-section through the calf of an infant eight months old just above the upper pole of the sheath of the extensor proprius hallucis. Note that between the fascia and the tendon there intervenes a layer of tissue known as the paratenon. Under higher magnification this tissue is seen to consist of fat cells and elastic fibers.

that the tendon is separated from the fascia by a band of tissue which under a high power is seen to be a loose fatty areolar structure containing a large number of elastic fibres. In the next section, taken $\frac{1}{4}$ inch lower (see Fig. 94), a cleft is visible which corresponds to the upper pole of the tendon sheath. This cleft, however, does not come into immediate contact with the tendon, but is separated from it by tissue which exactly resembles that of the previous section lying between fascia and tendon. In the next section, again $\frac{1}{4}$ inch

distal (see Fig. 95), the cleft is divided into two portions by a transverse band; whereas in the next, Fig. 96, this band has disappeared and the cleft separates the fascia from the tendon. To render these microscopical sections clearer, and to correlate them, a series of corresponding cross-sections and a longitudinal section are given in Fig. 97. From these it is evident that the loose areolar tissue which separates the tendon from
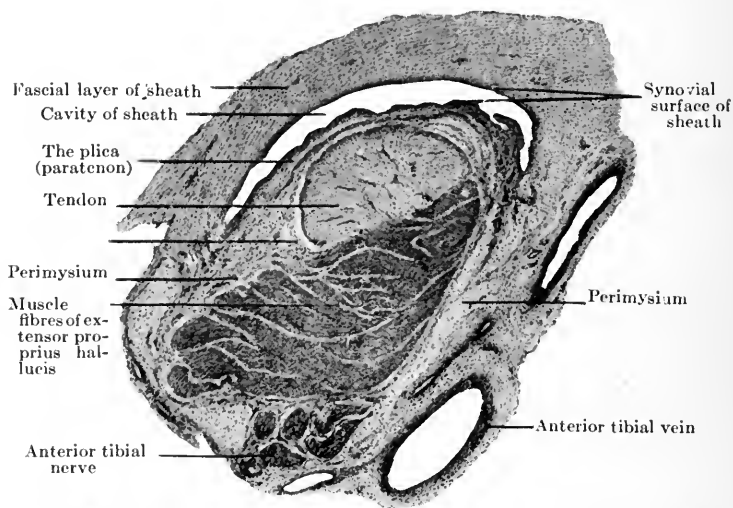
Fig. 94.—Microscopical cross-section through the calf of an infant eight months old at the level of the upper pole of the sheath of the extensor proprius hallucis. Note that the cleft corresponding to the sheath is separated from the tendon by the same type of tissue, which in the preceding section, lay between tendon and fascia (the paratenon).

the fascia above the sheath, extends downward into the sheath as a tongue-like projection which divides the upper end of the sheath into two portions—a deep pocket between the tongue-like projection and the tendon, and a superficial pocket between it and the fascia. This projection is known as the *plica,* and the tissue above the sheath separating fascia from tendon is known as the *paratenon.*

The significance of paratenon and plica in the gliding mechanism of the tendon becomes evident as soon as the muscle contracts and the tendon glides. Then it is seen that
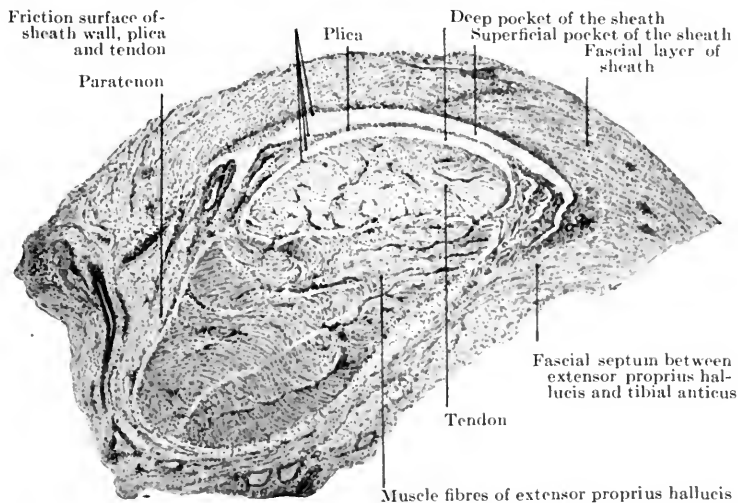
FIG. 95.—Microscopical cross-section through the calf of an infant eight months old ¼ inch distal to the preceding section. The cleft corresponding to the sheath is divided into two portions by a transverse band of loose connective tissue similar in structure to the paratenon—the plica.
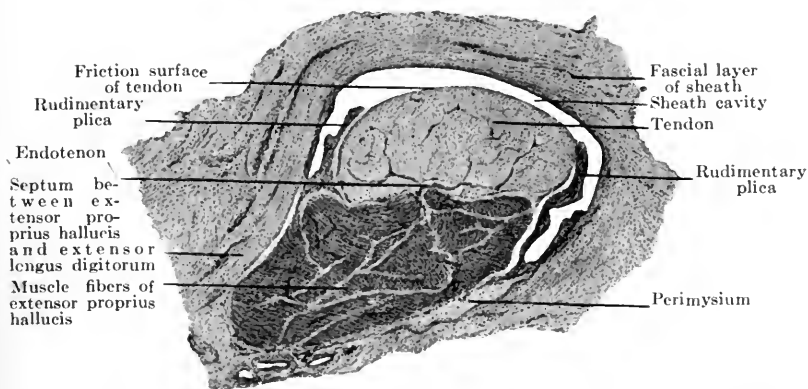
FIG. 96.—Microscopical cross-section through the calf of an infant eight months old, ½ inch distal to the preceding section. At this level the tendon sheath is directly interposed between the fascia and the tendon. The remnants of the paratenon are seen on each side as rudimentary structures.

the deep pocket of the sheath, namely that between plica and
tendon, becomes elongated, whereas the superficial pocket
becomes somewhat shallower (see Fig. 98). As the muscle
contracts still further, these changes become more pronounced
until when the muscle has reached the maximal point of con-
traction the deep pocket has become distinctly longer than
the superficial. It is clear that a kind of invagination has
occurred, and that the plica, acting as a kind of valve, has
allowed the tendon to glide freely, and at the same time has
maintained the sheath wall intact.
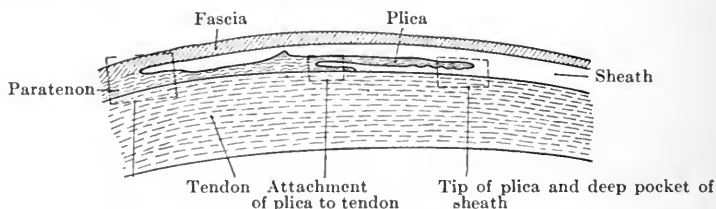
FIG. 97e.—Diagrammatic longitudinal section of the extensor proprius
hallucis tendon to correlate the four preceding cross-sections. Note that
the paratenon situated between fascia and tendon is prolonged downward
as a tongue-like structure (the plica), which divides the upper pole of the
sheath into two pockets: (1) a superficial, between fascia and plica, and (2) a
deep, between plica and tendon.

That some such valve-mechanism must be present is neces-
sitated by the anatomical relations of the fascia and the
bones which form the immovable channel through which the
tendon glides. To use a rough simile, the tendon corresponds
to the piston of a cylinder represented by the rigid bone and
the fascia attached to it. Just as it would be impossible for
the piston to glide to and fro within the cylinder, were it
rigidly attached at any point, so it would be impossible for
the tendon to glide within its cylinder unless some mech-
anism were present which could, because of its elasticity,
maintain the sheath as a closed cavity and yet be able to
follow the excursion of the tendon.

The essential in this gliding mechanism is the *paratenon*.
As before stated, this is a loose areolar tissue with an unusually
large number of elastic fibres. Because of the elasticity thus
imparted to it, it can be stretched 3 or 4 cm. without rupture
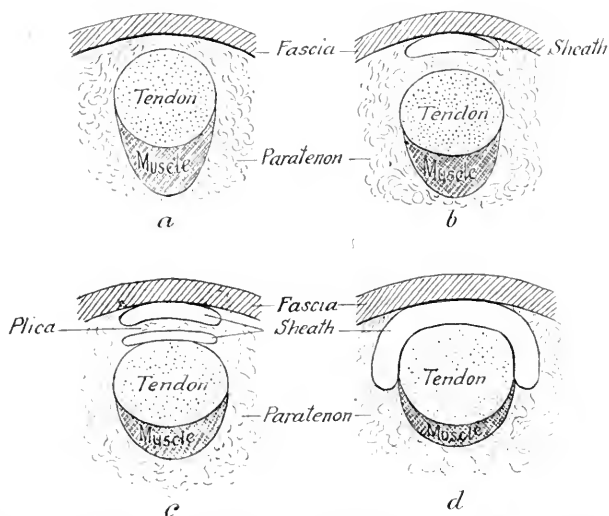
Fig. 97.—Diagrams representing the relations of the tendon to the para-
tenon and to the upper pole of the tendon sheath. *a*, Cross-section above
the upper pole of the sheath corresponding to Fig. 93; note that the para-
tenon intervenes between the tendon and the fascia. *b*, Cross-section
through the upper pole of the sheath corresponding to Fig. 94; note that
the sheath is separated from the tendon by the paratenon. *c*, Cross-section
¼ inch distal to the preceding, corresponding to Fig. 95; note that the
sheath is divided into a superficial and a deep portion by a band of paratenon,
termed the plica. *d*, Cross-section ½ inch distal to *c*, corresponding to Fig.
96; note that the sheath now intervenes between fascia and tendon.

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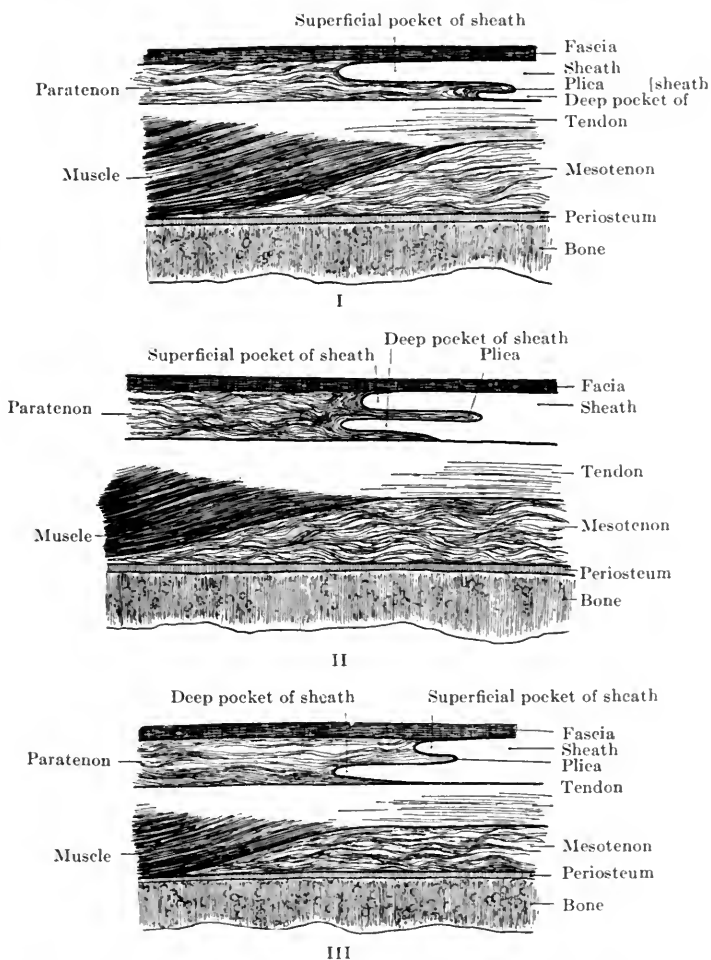
FIG. 98.—Three diagrammatic longitudinal sections of the tendon at its entry into the sheath, illustrating the valve-like mechanism which permits the gliding of the tendon between the rigid fascia and the bone. I, The muscle at rest. II, The muscle in mid-contraction. III, The muscle fully contracted. Note that the sheath is divided into two portions by the downward projection of a tongue of tissue (the plica). As the muscle contracts, pulling the tendon upward, the deep pocket of the sheath becomes elongated until, in the phase of complete muscular contraction, this deep pocket, which was originally shallow, has become much longer than the superficial pocket.
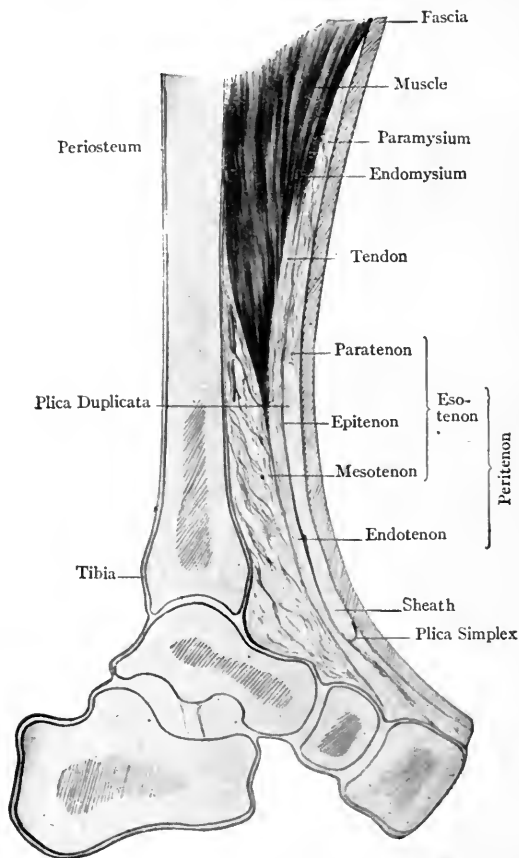
Fig. 99.—Diagrammatic longitudinal section illustrating the relation of the tendon to the surrounding connective tissue structures and to the sheath. The sheath is a sac containing fluid, interposed between tendon and fascia or bone, wherever the tendon changes its direction. It acts as a fluid buffer diminishing friction.   To permit gliding of the tendon between the rigid fascia and the bone it is surrounded by a peculiarly elastic tissue known as the paratenon, which is well adapted to follow the movements of the tendon without rupture of its fibers.   At the upper part of the sheath this tissue is prolonged downward as a tongue-like projection known as the plica.   Within the sheath the paratenon serves to attach the tendon to the bone by a delicate membrane through which the blood vessels run, corresponding to the mesentery of the intestines.   This is known as the mesotenon.   The mesotenon expands on the deep surface of the tendon (see Fig. 100), forming a delicate

of its fibres. For the surgeon, it is of particular importance to conserve the gliding function of this tissue in the performance of tendon transplantations, since it is the means of preventing adhesion between the tendons and the unyielding fascia.

The tendon sheath is interposed between the tendon and the fascia or bone, wherever the tendon has to change its direction. When no change in direction is present, as in the case of the Achilles tendon, there is no sheath. Of course, I use the term sheath here in its strict technical sense, as a synovial-lined structure containing a synovial fluid. It corresponds therefore somewhat to a bursa, and in some ways to a joint. Its function is to act as a fluid buffer preventing friction of the tendon against ligament or bone (see Fig. 99).

To the surgeon who wishes to follow nature's method, it is clear that in tendon plastics, so important a structure as the sheath must not be overlooked, and that if possible the normal relation between it and the tendon should be maintained.

The Mesotenon.—When the sheath of a tendon is opened and the tendon lifted out, a delicate connective-tissue membrane is seen connecting the tendon with the floor of the sheath. This structure, known as the mesotenon, transmits blood-vessels to the tendon and corresponds roughly to the mesentery of the intestine (Fig. 100). That portion of the tendon into which it is inserted is termed the hilus. It is always on the surface of the tendon least exposed to friction. Here the connective tissue of the mesotenon expands on the surface of the tendon, forming the *epitenon,* and sends connective-tissue strands between the tendon bundles, thus forming the *endotenon* (Fig. 101).

The Blood-vessels of the Tendon.—The results of injection experiments have shown that the current conception of the

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layer of connective tissue termed the epitenon. In this tissue the main blood vessels of the tendon have their longitudinal course. Paratenon, epitenon and mesotenon can be termed together the esotenon to differentiate them from the connective tissue within the tendon known as the endotenon. All the connective tissue structures associated with the tendon may be termed the peritenon.

tendon as practically bloodless is incorrect.   Though much less vascular than muscle or the surrounding loose connective tissue, the tendon contains numerous vessels, except near its friction surface.   Here practically no blood-vessels are visible. In general the vessels of the tendon are derived from three main sources: (1) from muscular branches; (2) from vessels
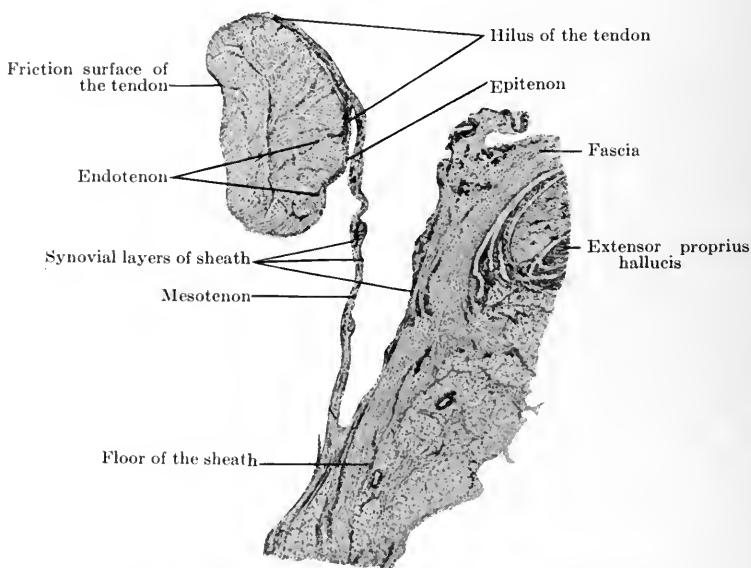
FIG. 100.—Microscopical cross-section of the tibialis anticus tendon drawn out of its sheath to show the relation of the mesotenon to the floor of the sheath and to the tendon.

running in the surrounding connective-tissue: paratenon, mesotenon, and the vincula; (3) from vessels of the bone and periosteum near the point of insertion of the tendon.   These vessels travel in the hilus of the tendon, in the epitenon, and in the connective-tissue septa between the tendon bundles (the endotenon) and anastomose freely by transverse and oblique branches.   Fig. 101, a transverse section through the flexor longus hallucis tendon, shows the longitudinal vessels cut transversely and some of the transverse and oblique

branches cut longitudinally.   The tendons are most vascular
near the insertion of the mesotenon; that is, near the hilus.
Here the numerous branches of the mesotenon ramify in the
epitenon and send numerous fine twigs into the tendon.
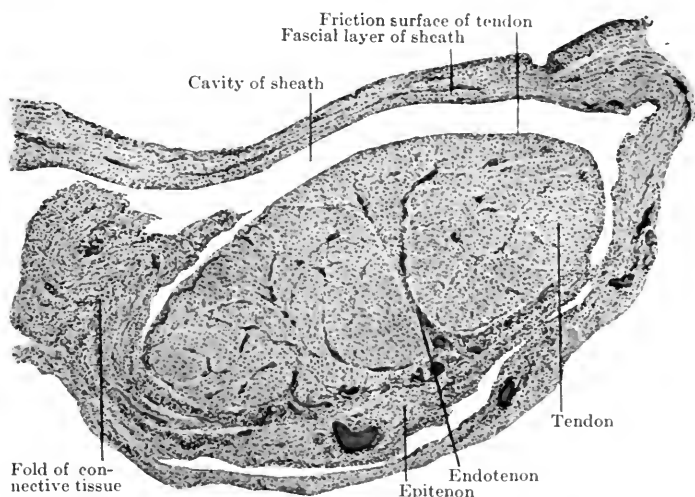
FIG. 101.—Microscopical cross-section through the flexor longus hallucis
tendon of an infant eight months old, to illustrate the situation of the blood
vessels of the tendon.   Note that the largest vessels run in the connective
tissue on the deep surface of the tendon (epitenon) and that smaller vessels
are present in the connective tissue speta (endotenon) between the tendon
bundles.   Near the gliding surface of the tendon no blood vessels are present,
since this corresponds closely in structure and in function to the cartilage of
the joint.   The nuclei of the tendon cells near the gliding surface, instead of
showing the usual elongated form, are round and closely resemble those of
fibro-cartilage.

The Tension of Tendons.—For many years, orthopædic
surgeons have been engaged in controversy as to the proper
tension under which transplanted tendons should be sutured,
one maintaining that the tendon should be sutured under the
greatest possible tension, another claiming that the tension
should be "moderate," and still a third, that there should be no
tension.   The solution depends upon a satisfactory answer to
the question: What is the normal tension of a tendon?   To
answer this physiological problem which, for some reason or

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other had never engaged the attention of physiologists or anatomists, I performed the following simple experiment. Under anæsthesia, the tendon of a dog was divided near the point of insertion, and to the proximal stump, which retracted one or more inches, owing to the pull of the muscle, a stout silk suture was attached and fixed to a spring scale.
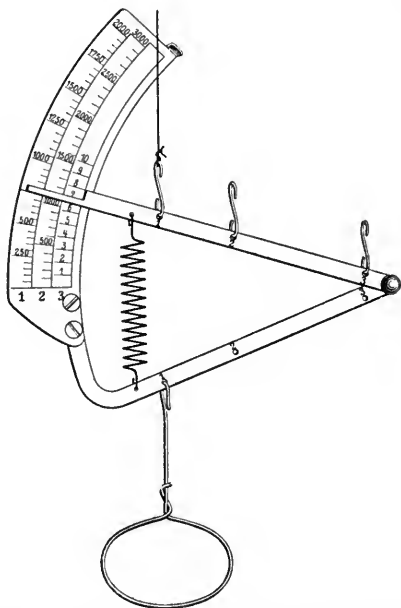
Fig. 102.—The spring balance used to test the tension of tendons. By shifting the position of the handle and the silk suture, readings can be taken from 25 grammes up to 10 kilogrammes.

By traction on the handle of this scale (see Fig. 102) the tendon stump could be pulled downward until it was brought in contact with the distal stump, and by means of the scale an exact reading could be made of the number of pounds' pull required to bring the tendon ends into apposition. This represented the traction to which the tendon was subjected by the muscle, since the operator had to exert just this much pull to overcome the muscular resistance. By varying the

conditions of the experiment, using larger and smaller muscles, light or superficial anæsthesia, resting muscle or muscles stimulated electrically, a great number of data were secured bearing upon the question of tendon tension.   Despite the great range in the degree of tension to which the tendon is subject, one fact remained constant in all the twenty animals tested experimentally and in the observations during operations on human beings: *when, under anæsthesia, the origin of an inactive muscle and its point of insertion are approximated to the physiological limit, that is, when the limb is passively held in the position which the active contraction of the muscle would cause it to assume, there is no tension on the tendon.*

The practical application of this law is simple.   To restore the normal tension the operator need only approximate origin and insertion of the muscle and tendon in question and suture the tendon to its new position without any tension whatever. For instance, in transplanting the peroneal tendon for the paralyzed tibialis anticus, the foot should be held in the position of calcaneovarus and the peroneal tendon sutured to its new point of insertion with just sufficient tension to render it taut.

General Principles of Tendon Operations.—On the basis of these and numerous other anatomical and physiological data, a system of operations has been worked out whose basic principle is the correlation of every step of the transplantation with the normal mechanics of tendon motion.   The surgeon must take cognizance not only of the course and insertion of the tendon as given in the anatomical textbooks, but of many other less known but equally important facts, such as the blood supply of the tendon, its fascial relations at various levels, its length, range of motion, its action, not merely in the normal situation, but when the point of insertion has been altered, the exact location and inner architecture of its sheath, the character and line of insertion of the mesotenon, and the bursæ associated with the tendon.

A physiological tendon operation must conform not only with the general surgical principles of absolute asepsis, minimal hæmorrhage and minimal traumatism, but also with the following demands:

1. It must whenever possible restore the normal relationship between the tendon and the sheath.

2. The course of the tendon from its original site to that of the paralyzed tendon must run through tissue adapted to the gliding of the tendon. Injury to the periosteum or the crude boring of a hole through fascia or interosseous membrane is inconsistent with this demand.

3. The normal insertion of the tendon must be imitated wherever possible by implanting the tendon directly into bone or cartilage, preferably at the insertion of the paralyzed tendon.

4. The normal tension of the transplanted tendon must be reëstablished and the physiological length of the transplanted muscle thus maintained.

5. The line of traction of the transplanted tendon must be such as to enable it effectively to do the work of the paralyzed tendon.

Although the chief field for the application of these operations is in the treatment of the residual paralyses of anterior poliomyelitis, they are also applicable to those paralyses resulting from gunshot injuries which are not amenable to nerve suture or neurolysis. Thus, a lesion of the anterior tibial nerve just after it has branched from the parent trunk can seldom, if ever, be cured by operation on the nerve, since the numerous fine muscular branches, given off at this level, cannot be found in the scar tissue. So, too, a lesion of the posterior interosseous nerve does not lend itself to direct operative treatment. Under these conditions tendon transplantations are indicated.

I shall not attempt describing all the transplantations which can be considered physiological, but only some of those which in my experience are available in the treatment of gunshot injuries.

Transplantation of the Extensor Proprius Hallucis for the Paralyzed Tibialis Anticus.—I have only twice had occasion to perform this operation, since it seldom occurs that a projectile produces an isolated injury of the nerves to the tibialis anticus. When, however, there is an isolated paralysis of this muscle, the following transplantation is an excellent method of relieving the tendency to valgus deformity.
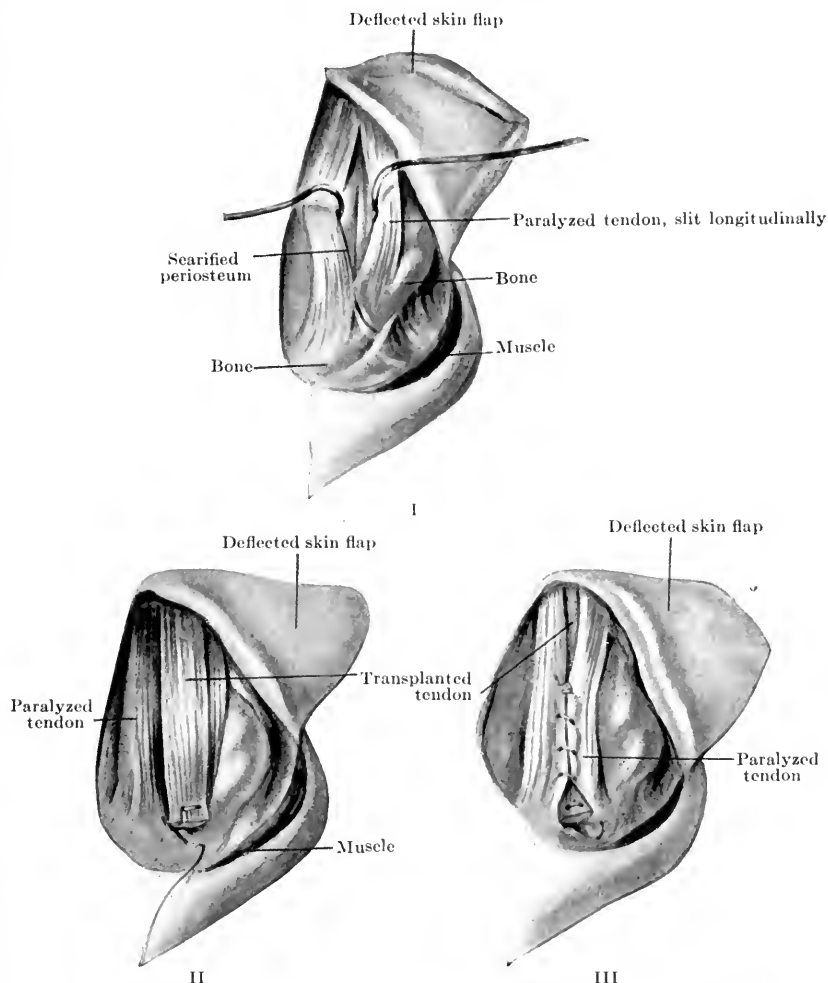
FIG. 103.—Method of anchoring the transplanted tendon. (*From Biesalski and Mayer.*) I. The paralyzed tendon is slit longitudinally at its insertion and the surface of the bone and periosteum are scarified to stimulate osteogenesis. II. The transplanted tendon, sutured by the stitch shown in Fig. 108, is firmly anchored between the halves of the split paralyzed tendon. The needle passes through cartilage or bone, ligament and muscles so as to get a mechanically firm grip. III. The halves of the split tendon are united over the transplanted tendon by a series of fine sutures, thus bringing the transplanted tendon into intimate contact with the traumatized bone. During the normal healing process, firm fixation occurs by the sixteenth day.

1. The first skin incision, 2 inches long, bowed with the convexity toward the sole of the foot, is made over the insertion of the tibialis anticus.

2. Preparation of the Implantation Site for the Extensor Hallucis.—The tendon of the tibialis anticus at its insertion is slit longitudinally for about 1 inch, and the bone or cartilage
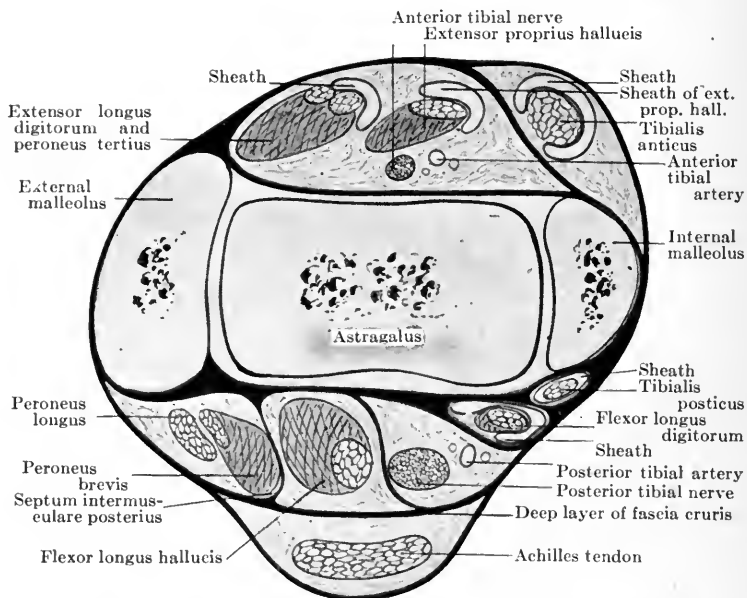
FIG. 104.—Semi-diagrammatic cross-section through the calf at the level of the upper pole of the extensor hallucis sheath. (*From Biesalski and Mayer: "Physiological Method of Tendon Transplantation."*)   Note that the tibialis anticus is separated from the extensor proprius hallucis and extensor longus digitorum by a strong fascial septum.

of the internal cuneiform is grooved for the reception of the extensor tendon (see Fig. 103).

The implantation site is prepared before the extensor tendon is laid bare, so as to avoid exposing it to the air more than is absolutely necessary.

3. The Incision over the Extensor Proprius Hallucis Tendon. —This runs in the line of the tendon from a point $1\frac{1}{2}$ inches above the tip of the internal malleolus to the middle of the first

metatarsal bone.   The reason for this long incision is evident, when the sheath of the tendon has been opened.   Then it is seen that the mesotenon attaching the tendon to the floor of the sheath is too well developed to allow withdrawing the tendon from the sheath through a small supramalleolar incision.

It is well, however, not to expose the tendon unnecessarily at this stage of the operation, but to leave it *in situ,* until all has been made ready for transferring it into the sheath of the tibialis anticus.
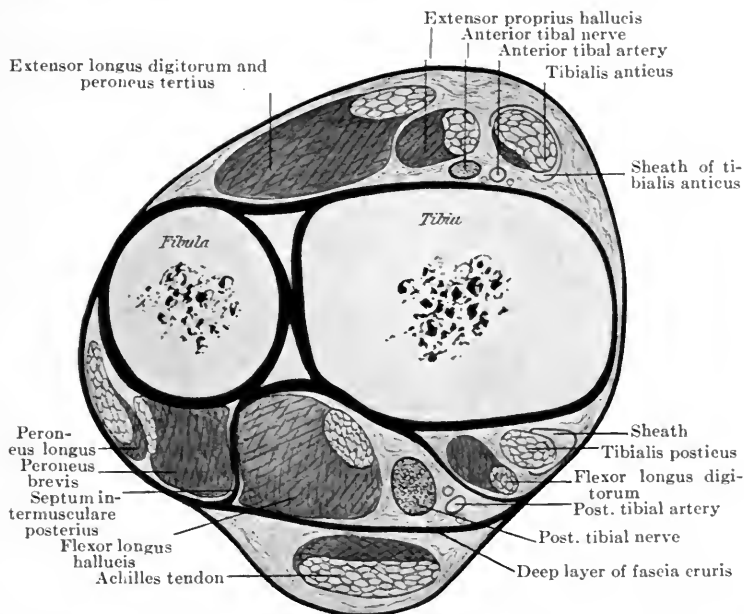
FIG. 105.—Semi-diagrammatic cross-section through the calf at the level of the upper pole of the tibialis anticus sheath $\frac{1}{2}$ inch proximal to the preceding section.   (*From Biesalski and Mayer: "Physiological Method of Tendon Transplantation."*)   Note that the three extensor muscles lie in the same fascial compartment.

4. This transfer requires an accurate knowledge of the fascial relations between the two tendons.   Fig. 104, a diagrammatic cross-section through the calf at the level of the upper pole of the sheath of the extensor proprius hallucis, shows the extensor and the tibialis anticus divided from one another

by a fascial septum derived from the fascia cruris. To run the extensor hallucis through this fascial septum would not be physiological. Fig. 105 at the level of the upper pole of the tibialis sheath, about ½ inch proximal to the preceding, shows the three anterior muscles of the calf lying within the same fascial compartment. This is the site of election. Here the operator can draw the extensor tendon into the sheath of the tibialis anticus, confident in the knowledge that serious postoperative adhesions will not result. Since this point lies slightly above the upper pole of the extensor hallucis sheath, the fascia over the extensor must be incised for 1 inch proximal to the sheath. The mesial fascial edge is
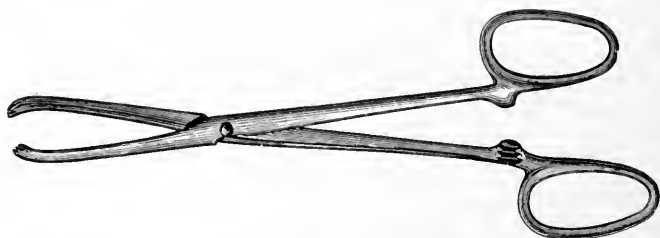
Fig. 106.—Clamp used to grasp the tip of the tendon during the operative manipulations. It enables the operator to hold the tendon firmly with a minimal degree of traumatization. (*From Biesalski and Mayer:* "*Physiological Method of Tendon Transplantation.*")

grasped with the clamp shown in Fig. 106 and raised until the operator sees the anterior tibial tendon shimmering through the paratenon, which separates it from the extensor hallucis. Here a small incision is made directly into the tibialis sheath (Fig. 107). An eye-probe is passed through this incision in the line of the tibialis tendon, made to puncture the lower end of the sheath, and to appear over the insertion of the tendon.

5. The sheath of the extensor hallucis tendon is then slit open its entire length. The tendon is divided near the middle of the metatarsal bone, its end grasped with the tendon clamp (Fig. 106) and the mesotenon divided close to the tendon until the operator reaches the lowermost muscle-fibres. The vessels of the mesotenon are thus sacrificed, but a large vessel which runs through the lowermost muscle-fibres can always be spared.

The tendon end is threaded with chromic catgut by the stitch shown in Fig. 108, the free ends of the suture are passed into the eye of the probe and the tendon thus readily drawn through the sheath of the tibialis anticus.

Withdrawing the tibialis anticus tendon from the sheath produces needless trauma and is unnecessary, since the sheath does not closely invest the tendon, but is large enough to accommodate two tendons.

Distal stump of extensor proprius hallucis
Divided tendon of extensor proprius hallucis
Tibialis anticus
Opening into sheath of tibialis anticus
The incised fascia
Lowermost muscle fibres of extensor proprius hallucis
Mesotenon
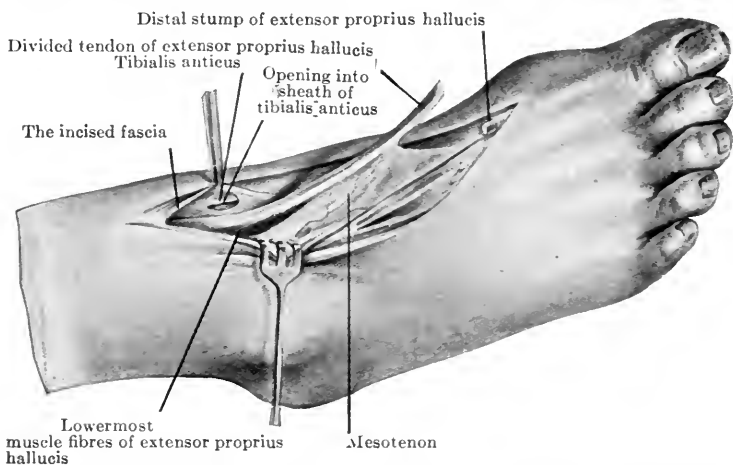
FIG. 107.—Transplantation of the extensor proprius hallucis for the paralyzed tibialis anticus tendon. (*From Biesalski and Mayer: "Physiological Method of Tendon Transplantation."*)   The implantation site over the insertion of the tibialis anticus has already been prepared (see Fig. 103).   The extensor proprius hallucis has been exposed from a point slightly above the upper pole of its sheath almost to the head of the metatarsal bone.   At the upper level of the incision a small opening has been made in the loose tissue (paratenon), which at this level (see Fig. 105) separates the extensor tendon from the tibialis anticus.   Through this opening the extensor tendon is drawn downward by means of an eye probe which traverses the sheath and emerges over the insertion of the tibialis anticus tendon.

6. Fixation of the Tendon.—Here the knowledge of the law of tendon tension is important, since otherwise the operator is likely to sew the tendon under too great tension and thus throw an unnecessary burden on the transplanted muscle.   It may be remembered that in outlining the physiology of tendons I

showed that when the muscle is relaxed under narcosis and its origin and insertion are approximated, the tendon itself, as well as the muscle-fibres, have a zero tension (see p. 143 *et seq.*). Therefore, to give the transplanted tendon the exact physiological tension, one must merely approximate the origin of the muscle and its new point of insertion (in this instance, by holding the foot inverted and flexed dorsally), draw the tendon downward until it runs in a straight line, and suture it under just sufficient tension to maintain this desired course.   With a
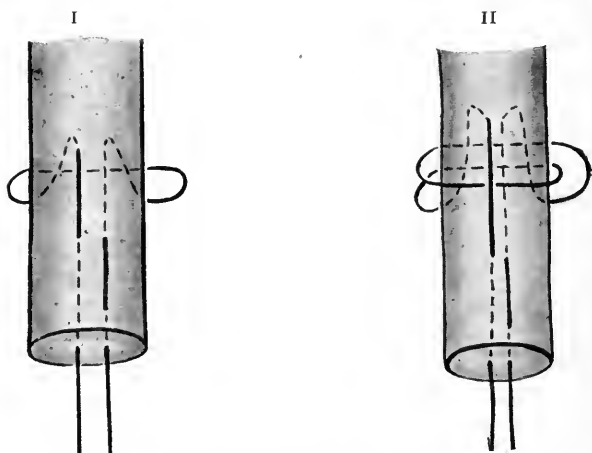
Fig. 108.—The fixation suture used in anchoring the transplanted tendon. (*From Biesalski and Mayer: "Physiological Method of Tendon Transplantation."*) I. A single transverse suture for small tendons.   II. A double transverse suture for larger tendons.

little experience the operator knows beforehand just how long the tendon must be to reach its new point of insertion and the chromic gut suture, inserted to draw the tendon through the sheath, can thus be used as the fixation suture.

The implantation site has already been prepared (see second step of the operation) by slitting the tibialis tendon lengthwise and traumatizing the periosteum of the internal cuneiform. The tendon, threaded by the fixation suture shown in Fig. 108, is now fastened securely between the two halves of the tibialis tendon.   The sutures are threaded on a stout cervix needle or an instrument resembling a shoemaker's awl, and are passed

through bone or cartilage, ligament, and fascia. The fixation must be mechanically fast. When properly executed it can withstand a traction of 20 to 30 pounds.

This mechanical fixation does not, however, meet the physiological demand, for firm though the suture is at the time of the operation, experimental work has shown that such a suture produces a necrosis of the tendon, and therefore there is a possibility that subsequently the tendon may slip from its moorings. This slipping, however, is prevented by suturing the paralyzed tibialis tendon over the extensor hallucis (Figs. 103 and 109). In this way the living tendon-cells of the extensor proprius hallucis above the fixation suture are brought
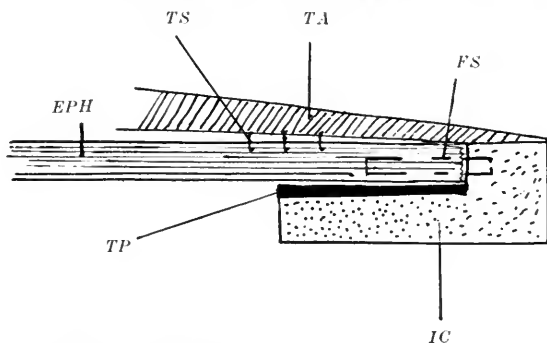
Fig. 109.—Diagram illustrating the principle of the physioloical tendon fixation. The fixation suture gives the mechanical stability; the adhesion of the tendon to the traumatised periosteum and to the superimposed tibialis tendon gives the physiological security. *TS*, Tendon sutures; *TA*, paralyzed tibialis anticus; *FS*, fixation suture; *IC*, internal cuneiform; *TP*, traumatized periosteum; *EPH*, tendon of the extensor propius hallucis.

into direct contact with the periosteum and with the tendon of the tibialis anticus. Thus the fixation is rendered physiological as well as mechanical, for in the healing process, even though the tendon distal to the fixation suture necroses, an intimate union above this point is bound to occur between the tendon and the traumatized periosteum.

7. The distal stump of the extensor tendon is fastened to the adjacent tendon of the extensor longus digitorum, the fascia is closed, and thus the normal ligaments of the foot are restored. The skin incisions are closed without drainage.

Conversion of the Tibialis Anticus into an Abductor and Pronator.—This operation is indicated in cases of paralytic

FIG. 110.—Transplantation of the tibialis anticus for the paralyzed everters of the foot. (*From Biesalski and Mayer: "Physiological Method of Tendon Transplantation."*)   The longitudinal incision in the course of the tibialis anticus tendon exposes it from the upper pole of its sheath to its point of insertion.

clubfoot, due to an inoperable lesion of the musculocutaneous nerve. Occasionally it can be employed in the spastic talipes

varus associated with a hemiplegia produced by an injury to the cerebral cortex. It should be performed only when a marked degree of correction is required, for the action of the muscle is so powerful as easily to produce an overcorrection. When slighter grades of varus are present, the extensor proprius hallucis should be used instead of the tibialis anticus. The two operations are so nearly alike that the description of the one suffices.

1. A 2-inch curved incision is made over the insertion of the peroneus tertius (see Fig. 111). Skin, fascia and subcutaneous tissue are retracted to form a flap.

2. The tendon of the peroneus tertius, which is almost always present, is then slit for several centimeters as in Fig. 103 and the metatarsal bones grooved for the reception of the tibialis anticus.

3. An incision is made in the course of the tibialis tendon from the upper pole of its sheath, $1\frac{1}{2}$ to 2 inches above the malleolus, to its insertion (Fig. 110). The sheath is opened near its upper pole. Here again the exact knowledge of the sheath, its limits and inner architecture is necessary for the neat execution of the operation.

4. It will be remembered that in describing the first operation attention was called to the fascial relations of the three anterior muscles of the foot: the tendons above the upper pole of the tibialis sheath lie in the same fascial compartment, then for about an inch the extensor proprius hallucis and the extensor longus digitorum lie in the same fascial compartment separated from the tibialis anticus by a fascial septum. From the level of the malleolus downward there are three such compartments, one for each of the three anterior muscles (Fig. 112). The transfer of the tibialis tendon is best made above the fascial septum separating it from the extensors, since in this way danger of adhesions is entirely avoided.

The lateral margin of the divided fascia just proximal to the upper pole of the tibialis sheath is retracted until the extensor longus digitorum is visible (Fig. 111). This level lies above the upper pole of the extensor sheath. To enter the sheath the loose connective tissue surrounding the extensor tendons—the paratenon—is incised until the bare
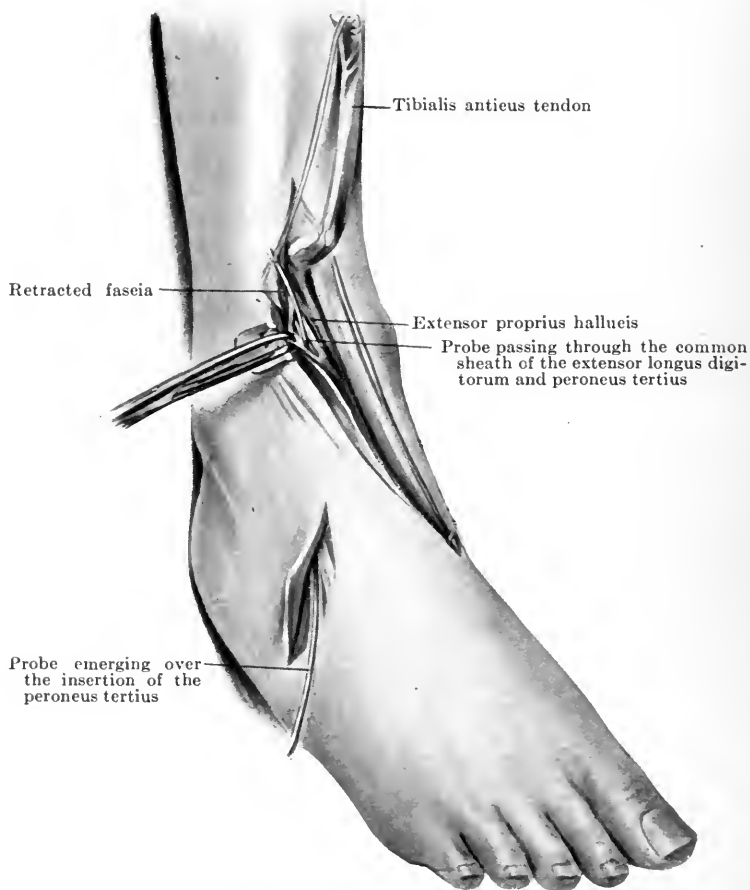
FIG. 111.—Transplantation of the tibialis anticus for the paralyzed everters of the foot. (*From Biesalski and Mayer: "Physiological Method of Tendon Transplantation."*) A convex incision is made over the insertion of the peroneus tertius. A probe is passed downward through the sheath of the extensor longus digitorum and made to emerge over the insertion of the peroneus tertius. By means of the probe the tibialis anticus tendon, which has been cut off at its insertion, preferably with a bit of the bone attached to it, is drawn downward through the common extensor sheath and fastened to the slit peroneal tendon by the technic shown in Fig. 103.

tendons cells are reached.   A probe passed along the tendon is then certain to enter the sheath.   Passing the probe through the sheath again calls for a knowledge of its inner architecture. All five tendons, the four extensors and the peroneus tertius are connected with one another by means of a common mesotenon.   The operator must be careful to pass the probe superficial to the tendons; otherwise he will draw the tibialis
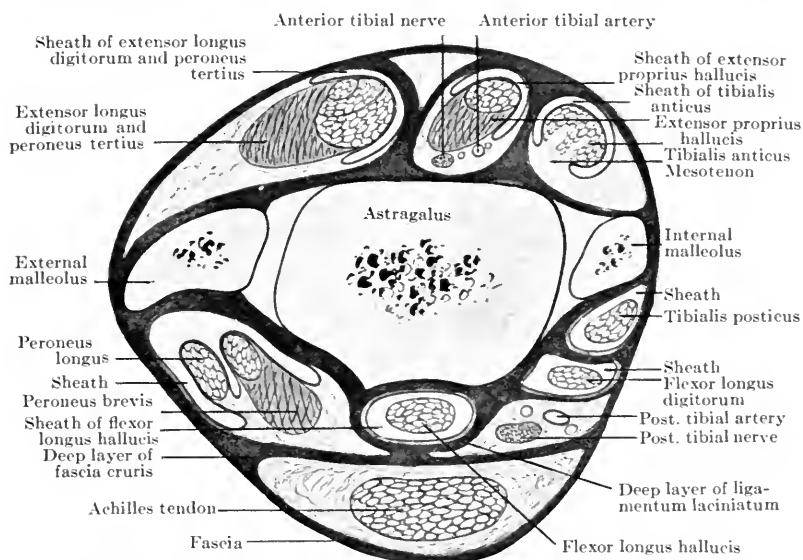
FIG. 112.—Semi-diagrammatic cross-section of the calf, through the tips of the malleoli, about $\frac{1}{2}$ inch lower than the section shown in Fig. 104.   Note that the three extensor muscles are divided from one another by dense fascial septa.   (*From Biesalski and Mayer: "Physiological Method of Tendon Transplantation."*)

anticus between the extensor tendons and thus tend to interfere with their function as well as its own.   The probe is guided in the direction of the peroneus tertius, made to puncture the lower pole of the sheath, and to appear between the fascia and the tendon near its insertion.

5. The sheath of the tibialis anticus is now slit open its entire length and the fascia below the sheath incised until the insertion of the tendon is visible (Fig. 110).   The tendon must

be divided as near the bone as possible; otherwise it would not be long enough to reach its new point of insertion. It is advisable to remove a little bone with the tendon since this renders the fixation doubly secure. The tendon is then threaded with stout chromic gut as in Fig. 108 and freed from its mesotenon until it can run a direct course into the sheath of the extensor digitorum and peroneus tertius.

6. The tendon is drawn through the sheath by means of an eye-probe, and fastened to the bone and to the peroneus tertius tendon by the technic described in the first operation. Care must be taken that the course of the tendon is straight and that the muscle is not twisted.

Transplantation of the Peroneus Longus for the Tibialis Anticus.—The operation is indicated in severe cases of spastic or paralytic talipes valgus, in which transplantation of the extensor proprius hallucis would be insufficient to restore muscular balance. When combined with transplantation of the peroneus brevis to the outer side of the dorsum of the foot (conversion of the peroneus brevis into a dorsal flexor) it can be performed to correct the foot drop subsequent to an inoperable lesion of the anterior tibial nerve involving all the extensor muscles. This operation possibly better than any other illustrates the advantages of the physiological method of tendon transplantation. The operation as usually performed does not efficiently replace the paralyzed tibialis anticus, for unless the peroneal tendon runs through the sheath of the tibialis tendon a supinating effect is impossible. This fact can readily be demonstrated by experiments on the cadaver as well as by clinical experience. The operator, however, faces a grave difficulty in running the peroneal tendon from its original site to the sheath of the tibialis anticus, for the two muscles are separated throughout their entire length by a well-developed fascial wall—the septum intermusculare anterius. To overcome this difficulty, a fascial plastic is necessary.

The steps of the operation are as follows:

1. Incision over the insertion of the tibialis anticus as in the first operation, and preparation of the implantation site by slitting the tibialis tendon and grooving the internal cuneiform.
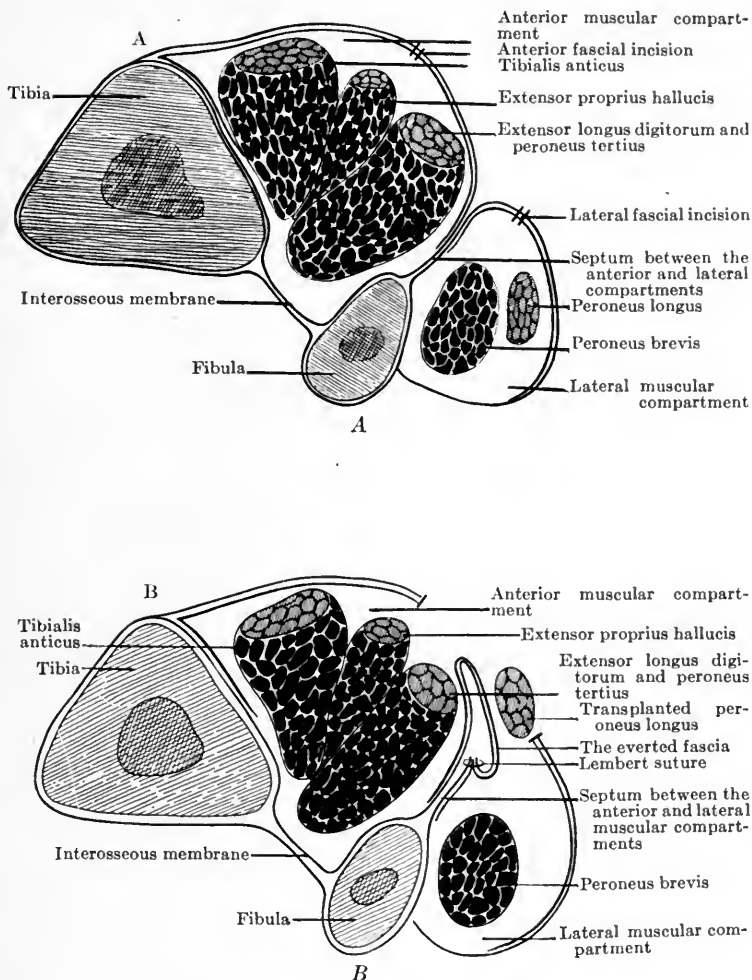
FIG. 113.—Diagrammatic cross-sections of the calf illustrating the principle of the fascial plastic for transfer of the peroneus longus from its compartment to that of the tibialis anticus. (*From Biesalski and Mayer: "Physiological Method of Tendon Transplantation."*) *A.* The incisions over the lateral and anterior muscular compartments. *B.* The eversion of the fascia turning the deep surface, coated with paratenon, outward to act as a bridge over which the peroneal tendon can glide.

11

2. A 1 inch incision near the upper pole of the tibialis sheath enables one to open the sheath and to pass a probe threaded with a guide-suture through it to the insertion of the tendon.   The probe is drawn entirely through, leaving the guide-suture in place.

3. The third skin incision is made over the peroneus longus tendon from the middle of the calf to the cuboid.   This long incision is necessary, for unless the tendon is freed almost to the middle of the calf it cannot be given a proper line of traction.   The upper end of the incision curves anteriorly so as to permit the execution of the fascial plastic.   The skin and subcutaneous tissues above the malleolus are retracted from the underlying fascia cruris until not only the peroneal muscles, but also the muscles of the anterior group—the extensors—are visible.

4. *The Fascial Plastic.*—Experimentally we know that the boring of a hole through the fascial septum tends to produce adhesions, whereas it is equally evident that the deep surface of the fascia from the middle of the calf downward is unusually well adapted to the gliding of the tendon, because it is clothed with the elastic paratenon.   Therefore, instead of ripping a hole through the fascia with the dressing forceps it is carefully incised first over the peroneal compartment, then over the anterior muscular compartment (see Fig. 113).   This latter incision is made to outline a flap (Fig. 114), which is inverted so as to expose the paratenon clothing its deep surface, and sutured by a Lembert stitch to the edge of the inverted fascia of the lateral fascial compartment (see Fig. 114).   The stitch itself is taken as near as possible to the fibula, so as to bury it in the muscular fibres of the peroneus brevis.   By this simple procedure a physiological path for the peroneal tendon is constructed.   The fascial incision must be somewhat longer than at first thought seems necessary, because the tendon runs not transversely but slanting from above downward.

5. An eye-probe is then passed from the upper pole of the tibialis sheath beneath the fascia cruris and made to appear in the region of the fascial plastic.   The upper end of the guide suture lying in the tibialis sheath (second step of the operation) is drawn beneath the fascia by means of the probe.   The

guide suture thus runs from the fascial plastic beneath the fascia cruris into the tibialis anticus sheath, downward through
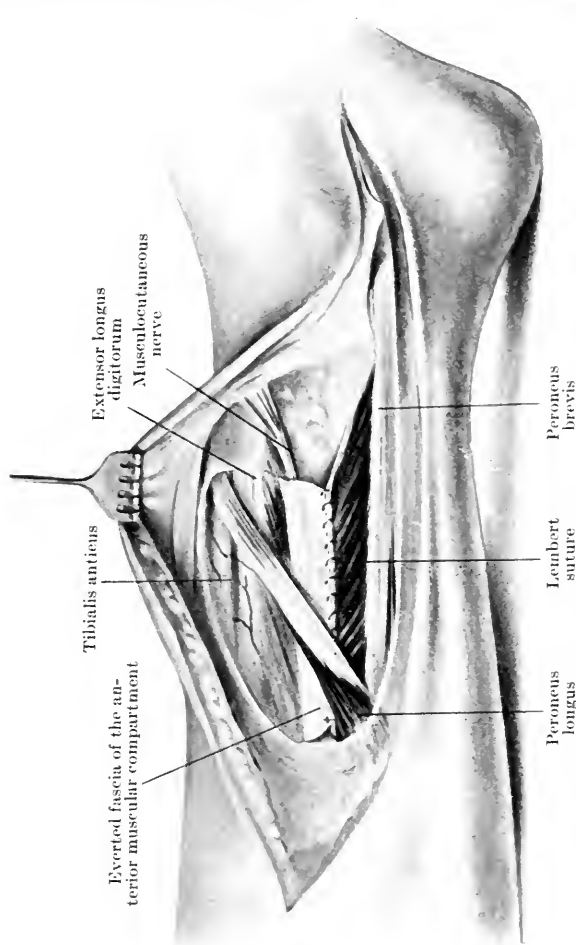
Fig. 114.—Transfer of the peroneus longus for the paralyzed tibialis anticus. (From Biesalski and Mayer: "Physiological Method of Tendon Transplantation.") The fascial plastic diagrammatically represented in Fig. 113 has been executed and the peroneus longus tendon is seen passing over the everted fascia of the anterior muscular compartment to enter the upper pole of the tibialis anticus sheath.

the sheath and out near the insertion of the tibialis tendon. It serves to draw the peroneal tendon along this course.

6. The peroneal tendon is now freed by prolonging the fascial

incision already made over its upper end, downward until the sheath has been opened, usually 1 to 2 inches above the malleolus, and then along the sheath to the groove in the cuboid where the peroneal tendon passes into the sole of the foot. When the peroneal tendon is divided at this point it reaches exactly the desired insertion on the inner border of the foot. It is threaded with the fixation suture, freed from its mesotenon, and by means of the guide suture drawn over the

FIG. 115.—Photographs illustrating the effect of transplanting the peroneus longus tendon for spastic flatfoot. (*From Biesalski and Mayer: "Physiological Method of Tendon Transplantation."*) *A*. Before the operation. *B*. Standing after the operation. *C*. Showing the power of voluntary inversion of the foot subsequent to operation.

fascial bridge downward through the tibialis sheath.   Fixation to the internal cuneiform, as in the first operation.

The fascial incisions are closed wherever possible, not only to restore the normal anatomical relations, but also as far as possible to prevent postoperative hæmorrhage.

Transplantation of the Flexor Longus Hallucis and One of the Peronei (Either Longus or Brevis) for Paralysis of the Gastrocnemius and Soleus Muscles.—*Indications.*—In military practice this operation is indicated but seldom, since it rarely or never occurs that the nerves of these muscles are

injured without a lesion of the main trunk which supplies the flexor longus hallucis.   Occasionally, however, after extensive loss of substance due to shell injuries, the gastrocnemius and soleus have so little power left that an operation is necessary to reinforce them.   If something is not done to restore the normal muscular balance, a pes cavus (hollow-foot) is almost certain to develop, since the unopposed pull of the short
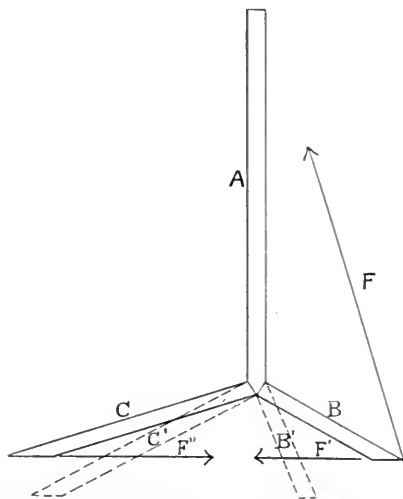
Fig. 116.—Diagram illustrating the formation of a hollow foot as result of paralysis of the Achilles tendon. A, Calf; B, the os calcis; C, the anterior portion of the foot.   Normally the position of B is maintained by the upward pull of F, representing the Achilles tendon and the forward pull of F', representing the short muscles of the sole of the foot and the plantar fascia.   If the gastrocnemius and soleus are paralyzed F becomes zero allowing F' to pull the os calcis forward into the position B'.   At the same time the pull of the plantar muscles on the front of the foot becomes sufficiently strong to bring C into the position C'.

plantar muscles causes the os calcis to tilt, as indicated in Fig. 116.

Technic.—The skin incision is best made after the manner described by Sir Robert Jones, namely in the transverse direction with or without the excision of an ellipse of skin.   The healing of the transverse incision produces more or less scar

tissue which helps draw the posterior tip of the os calcis upward.   The ends of the incision must extend sufficiently far
to permit the identification of the peroneal tendon on the outer
side and of the flexor hallucis on the inner side.   The peroneal
tendons are readily found just back of the external malleolus.
It is of no significance which one is selected for the transfer,
since the change in the course of the tendon is comparatively
slight and does not necessitate interference with the lowermost
muscular fibers.
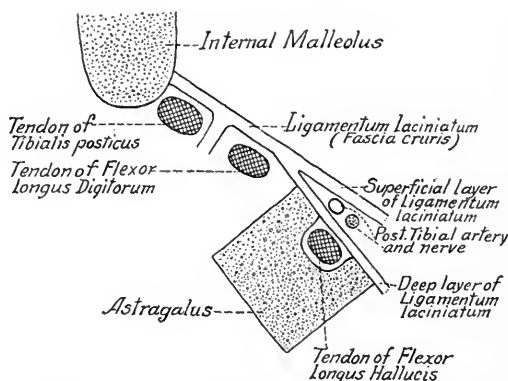
Fig. 117.—Diagram illustrating the relation of the flexor longus hallucis
to the fascial planes at the bend of the ankle.   To expose the tendon, the
superficial layer of the ligamentum laciniatum must first be incised, the posterior tibial artery and nerve drawn toward the internal malleolus exposing
the deep layer of the ligament which is attached directly to the astragalus.
By incising over the groove in the bone the flexor longus hallucis tendon is
exposed.

To find the flexor longus hallucis accurate anatomical knowledge is necessary.   The tendon at this point of its course lies
in a groove of the astragalus, covered by a band of fascia known
as the deep layer of the ligamentum laciniatum, a thickened
portion of the fascia cruris (see Fig. 117).   To find it, the
superficial layer of the fascia is first incised, exposing the nerve
and the artery.   These are drawn toward the internal malleolus, laying bare the deep layer of the fascia.   The inexperienced surgeon then has the impression that he is directly

against the bone and that the flexor tendon is absent. Careful examination, however, will indicate where to incise the fascial layer so as to find the tendon in the bony groove.

Before the tendons are exposed, the operator has, as in the previous transplantations, prepared the site of implantation by freeing the skin of the os calcis so as to lay bare the Achilles tendon at its point of insertion. The tendon is slit longitudinally and the periosteum traumatized. On each side the slit is prolonged laterally so as to form a path directly through the Achilles tendon for the tendons to be transferred. Each of these is sutured by the stitch shown in Fig. 108, drawn through the slit in the tendon and fastened securely to the os calcis. The operation is completed by an interrupted skin suture.

In instances in which there is a marked relaxation of the Achilles tendon, it is wise to reef it. If in addition the posterior portion of the joint capsule has been markedly overstretched, it too should be shortened by inserting several strong mattress sutures.

At the knee, no sheaths are present, since friction of the quadriceps and patella tendons against the bone is prevented by the interposition of the quadriceps bursa and the knee-joint, which act as fluid buffers in exactly the same way as a tendon sheath. In **transplantations at the knee,** therefore, the technic must be modified to meet the changed anatomical conditions. Here the subcutaneous route is more suited to the transplanted tendon, since the subfascial would tend to lock the tendon beneath the iliotibial band. The most frequent operation is the transplantation of the biceps tendon, with or without one of the inner hamstrings, to replace a paralyzed quadriceps extensor. Though the biceps alone suffices to give extensor power, the results are bettered by combining it with one of the inner group of flexors, since the resultant line of traction is directly upward, instead of upward and outward, as when the biceps alone is transplanted.

The steps of the operation are as follows:

1. *Preparation of the Implantation Site.*—A 3-inch vertical incision in the midline exposes the quadriceps tendon and the upper two-thirds of the patella. Two osteoperiosteal flaps

are deflected from the latter by a T-shaped incision, as indicated in Fig. 118.

2. *Reefing of the Quadriceps Tendon.*—Two strong mattress sutures are inserted, one in either side of the patella, so placed as to draw it upward to the physiological limit.   This is done so as to avoid breaking the law regarding suture of tendons under normal tension.   Were the transplanted biceps tendon sutured under the normal tension, the patella would not be sufficiently taut, but would slip downward.   Therefore, when
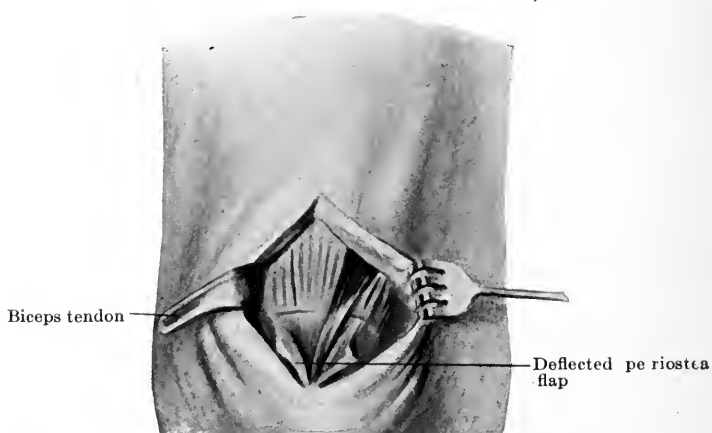
FIG. 118.—Transplantation of the biceps and of the gracilis for paralysis of the quadriceps femoris. (*From Biesalski and Mayer:* "*Physiological Method of Tendon Transplantation.*")   The illustration shows the manner of deflecting two triangular flaps from the surface of the patella.   These flaps consisting of tendon and periosteum, expose the surface of the bone to which the transplanted tendons are attached by the suture shown in Fig. 108.

the transplanted muscle contracted, part of its force would be expended in drawing the patella upward, instead of being utilized to extend the leg.

3. *Exposure of the Biceps Tendon.*—The incision runs along the mesial border of the tendon, from the junction of the middle and lower thirds of the femur to its insertion into the head of the fibula.   The external popliteal nerve is identified and drawn aside.   In freeing the tendon from its insertion two

facts must be borne in mind: *first*, the tendon is long enough to reach the patella only on condition that its full length be secured. It is wise to make certain of sufficient length by removing a piece of the fascia of the calf with the tendon. *Second*, the tendon is intimately associated at its insertion with the external lateral ligament of the knee-joint. Since injury to this important ligament impairs the stability of the joint, it should be carefully avoided.

Biceps tendon

Gracilis tendon

Periosteal flaps sutured over the transplanted tendons
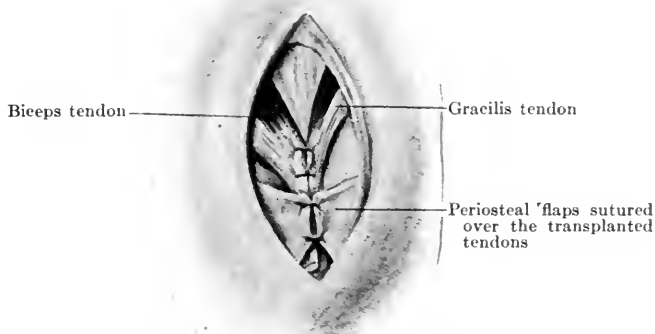
Fig. 119.—Transplantation of the biceps and of the gracilis for paralysis of the quadriceps femoris. (*From Biesalski and Mayer: "Physiological Method of Tendon Transplantation."*)   The two tendons, firmly sutured to the patella by the method shown in Fig. 109, are covered by the periosteal flaps and thus held tightly against the denuded bone. Several sutures are taken uniting the two tendons to one another, so that their line of traction is longitudinal, corresponding to that of the paralyzed muscle.

The tendon and the lowermost muscle fibres are freed upward until the operator is assured that their line of traction, when transplanted, will imitate that of the quadriceps extensor.

4. *Transfer of the Biceps Tendon and Fixation.*—Beginning at the anterior incision a subcutaneous channel is bored upward and outward to the point where the biceps has been freed. The channel must be sufficiently roomy to accommodate the

transplanted tendon and the lowermost muscle fibres.   In
performing the transfer care must be taken not to produce
a torsion of the muscle.   The tendon is fastened to the patella
by the suture illustrated in Fig. 108.

5. If possible one of the inner hamstring group—preferably
the gracilis or the semitendinosus—is transplanted in a similar
way.   The two transplanted tendons are united above the
insertion (see Fig. 119) so as to make their line of traction
correspond to the long axis of the thigh.

6. *Closure of Skin Wounds.*

For the tendons of the hand two groups of operations are
applicable: *first,* that for paralytic conditions; *second,* for
traumatic injuries of the tendons.

Fig. 120.—Two exposures on one plate illustrating the power of extension
in a case of complete paralysis of the quadriceps femoris subsequent to trans-
plantation of the biceps and of one of the inner ham string muscles.   Exten-
sion is possible against the weight of a 5 lb. sand bag.   (*From Biesalski and
Mayer: "Physiological Method of Tendon Transplantation."*)

Operation for Musculospiral Paralysis.—The method of
transplantation is based upon the fact that extension of the
distal phalanges is rendered possible by the action of the inter-
ossei and lumbricales.   Therefore the transplanted tendons
need not be utilized to extend the fingers, but can be sutured
directly to the metacarpus to produce extension of the wrist.

This insertion has two advantages: (*a*) implantation of the tendon into bone instead of to tendon; (*b*) vigorous flexion of the fingers, as in making a fist, an action for which extension of the wrist is necessary, can be performed more effectively if the transplanted tendon is sutured, not to the extensor communis digitorum, as generally advised, but to the metacarpus.

Since extension of the thumb is due solely to action of muscles supplied by the musculospiral, a special tendon must be transferred to the extensor longus pollicis. I advise the flexor carpi ulnaris for this purpose, since its line of traction when transplanted corresponds closely to that of the long extensor of the thumb. To extend the wrist, the flexor carpi radialis is used.

The steps of the operation are as follows:

1. *Preparation of the Implantation Site.*—A 1½-inch slightly curved incision exposes the insertion of the extensor carpi radialis longus and brevis. Either one of these tendons is slit longitudinally (see Fig. 103) and the periosteum at the insertion scarified.

2. *Preparation of the path* through the sheath of the extensor carpi radialis longus and brevis.

A 1½-inch vertical incision is made over the upper pole of the sheath, the sheath opened, and an eye-probe threaded with a loop of silk passed downward through it to the insertion of the tendons. As the sheath closely invests the two tendons, leaving scant room for a third, it is advisable to withdraw one of the tendons from it. This is done by dividing a tendon 1 inch above its insertion, incising its mesotenon as far upward as possible and then withdrawing the tendon from the sheath through the lower angle of the second skin incision.

3. *Exposure of the Flexor Carpi Radialis.*—A 7-inch incision exposes the tendon from the middle of the forearm to the annular ligament (see Fig. 121). This must be divided and the tendon exposed where it courses through its bursa, which corresponds closely to a short tendon sheath. In so doing the operator must sever the fibres of some of the short muscles of the thumb. It is necessary to free the tendon down to a point as near its insertion as possible, otherwise it is not long enough

to reach the dorsum of the metacarpal bones.   After dividing
the tendon near its insertion, it is dissected upward until the
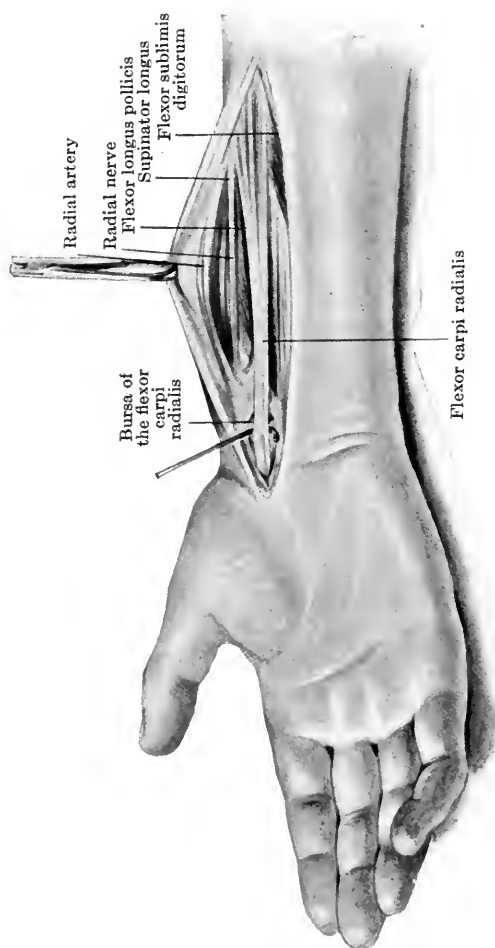
Fig. 121.—Transplantation of the flexor carpi radialis tendon for the paralyzed extensors of the wrist. (From Biesalski and Mayer: "Physiological Method of Tendon Transplantation.") The tendon must be divided below the annular ligament, to render it sufficiently long to reach the insertion of the extensor carpi radialis longior or brevior.

desired line of traction can be secured—usually about half-
way to the elbow.

4. *Transfer of the Tendon and Fixation.*—A subcutaneous channel is bored from this point to the upper end of the sheath of the extensor carpi radialis longus and brevis, through which the tendon is drawn by means of the guide suture (see second step of operation). It is fastened to the insertion of the extensor tendon by the technic already described in the previous operations.

5. *Exposure of the Tendon of the Extensor Longus Pollicis.*— This is found just to the ulnar side of the upper pole of the sheath of the extensor carpi radialis longus and brevis, so that additional incisions are unnecessary. It is to be observed that its course is oblique—from the ulnar side downward toward the radial side.   The tendon is divided at the musculo-tendinous junction.

6. *Exposure of the Flexor Carpi Ulnaris Tendon.*—This tendon is freed by a 6-inch incision along the ulnar border of the arm.   It is divided close to its insertion into the pisiform bone.   In dissecting it upward, the operator must divide some of the muscular fibres which have their origin from the ulnar; with care this division can be made parallel to the muscular fibres, so as not to produce any ragged edges.
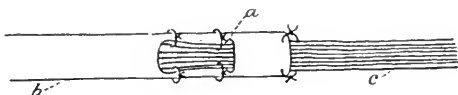
Fig. 122.—Suture of tendon to tendon when overlapping is possible. *a*, Button-hole opening; *b*, flexor tendon; *c*, carpi ulnaris tendon of extensor longus pollicis.

7. *Transfer and Fixation.*—The transfer is made by the subcutaneous route.   Then it is seen that the line of traction of the transplanted tendon corresponds closely to that of the extensor longus pollicis.

The fixation cannot be made to the bone, since the tendon is too short for that, but must be made to the paralyzed tendons.   A button-hole opening is made in the flexor tendon about $\frac{1}{4}$ of an inch from its free end (see Fig. 122) through this opening the extensor tendon is threaded, and the two tendons are firmly united by five or six fine chromic gut

stitches, so planned as to flatten the tendons against one another. To promote firm adhesion of the tendons, it is well to traumatize slightly the surfaces of the tendons which are brought into apposition.

8. *Closure of all skin wounds by continuous sutures.*

Operations for Median Nerve Paralysis.—In my own experience I have never had occasion to perform tendon transplantation for this type of paralysis. When all hope of recovery of the median nerve has to be abandoned, the tendon transfer would however be indicated.

A. If the ulnar nerve is intact: (*a*) The outer tendons of the flexor profundus are inserted into the inner tendons of the same muscle. (*b*) The tendons of the flexor sublimis are inserted into the tendon of the flexor carpi ulnaris. The extensor carpi radialis longior is attached to the flexor longus pollicis (Jones). The technic of the suture resembles that described in the preceding operations.

B. If the ulnar nerve also is paralyzed, the extensor carpi radialis longus and brevis may be utilized to activate the paralyzed tendons.

Transplantations for Injuries to the Tendons of the Fingers. —Thus far I have described tendon operations for paralytic conditions. In the succeeding paragraphs I shall outline a number of transplantations applicable to gunshot injuries of tendons in which direct union of the retracted tendon ends is impossible. At the beginning of this chapter it was stated that one of the commonest lesions seen in military practice is a perforating wound of the hand. The wound of entrance is usually on the palmar aspect, the larger star-shaped wound of exit is on the dorsum. Almost always one or more metacarpal bones are fractured and the flexor and extensor tendons of one or more fingers are completely severed. Such an injury leaves the patient with a badly crippled hand, since one or more fingers are not merely useless but in the way. Despite the usual demands for amputation of the helpless members it is advisable to conserve wherever possible by means of tendon operations. These operations cannot be considered in the same category as the transplantations described in the preceding pages, since from the nature of the injury it is impossible to utilize

a tendon-sheath as a path for the transferred tendon, and since the transferred tendon must be sutured to another tendon instead of being attached to the bone. In other respects, however, they conform to the principles of the physiological method.

The operation for the severed flexor tendons consists in transplanting the sublimis tendon of the adjacent finger and suturing it to the distal end of the injured flexor profundus tendon; that is, two adjacent fingers are supplied with two profundi tendons, since the one sublimis tendon is converted by the operation into a deep flexor. The steps of the operation, which is best performed under local anæsthesia, are as follows. For purpose of illustration I assume that both flexor tendons of the middle finger have been severed and that a mass of scar tissue the size of a fifty-cent piece occupies the mid-palmar region and is densely adherent to the bone. The first incision runs from a point 2 inches distal to the annular ligament in a line with the tendons of the index-finger to the proximal phalanx of this finger (see Fig. 123). The incision is deepened through the palmar fascia, until the sublimis tendon is visible throughout its course. The second incision is made distal to the scar tissue over the severed flexor tendons of the middle finger; it is about $1\frac{1}{2}$ inches long, slightly bowed, with the convexity toward the little finger, and extends to the base of the middle finger. The flexor tendons are then dissected free from the adhesions which usually bind them down. The operator must pay particular attention to this step since adhesive bands frequently extend well into the sheath. When properly freed, gentle traction on the flexor profundus tendon should produce complete flexion of the finger. The flexor profundus should be freed from the sublimis tendon, and about 1 inch of the latter excised. This is necessary because of the tendency to adhesions between the flexor profundus and flexor sublimis, which interfere with the action of the deep flexor. A subcutaneous channel is then bored with a dressing forceps from the proximal end of the first incision to the second incision. This step of the operation is usually rather difficult owing to the presence of scar tissue. It is better to give the channel a slightly curved direction, since a straight course would

necessitate boring between scar tissue and bone; the slight curve tends to be obliterated by the action of the tendon as soon as active motion has begun, whereas boring between scar tissue and bone tends to produce adhesions which nullify the effect of the operation. When a channel sufficiently roomy to accommodate the tendon has been bored, the sub-
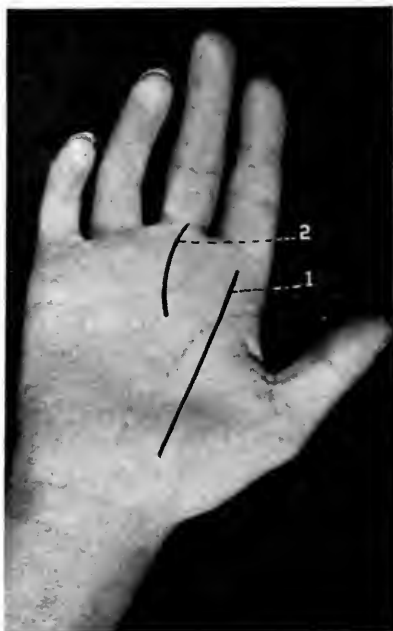
Fig. 123.—The incisions for transplantation of the flexor sublimis tendon of the index finger for the severed flexors of the middle finger.   1, First incision; 2, second incision.

limis tendon of the index-finger is divided at the metacarpophalangeal joint, dissected away from the deep tendon and as rapidly as possible, so as to avoid drying, is drawn through the subcutaneous channel.

The final step of the operation consists in suturing the transplanted tendon to the flexor profundus tendon of the third

finger. The suture may be performed in two ways. The usual technic is that already described on page 171: a button-hole opening is made in the tendon of the injured finger about a quarter of an inch from its severed end, the sublimis tendon is threaded through this opening; and the two tendons are united by fine interrupted chromic gut sutures. Another method of tendon suture is indicated if the tendons are friable
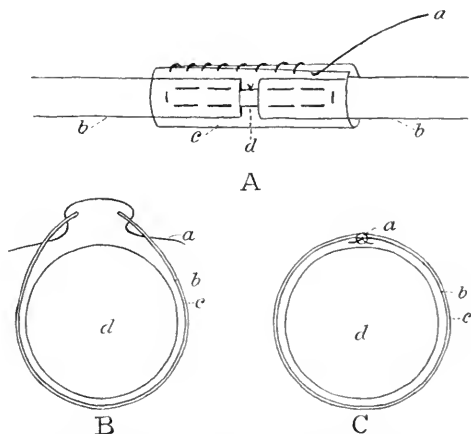
Fig. 124.—Suture of tendon to tendon, when overlapping is impossible. The suture is reinforced by a free transplantation of fascia from the calf. A, longitudinal diagrammatic sketch showing the Lembert suture in process of application which closes the tube of fascia overlapping the tendons; a, Lembert suture; b, tendon; c, transplanted fascia; d, Lange suture. B. Diagrammatic cross-section of the tendon and transplanted fascia indicating the manner of inserting the Lembert suture; a, suture; b, fascia (superficial surface turned toward the tendon); c, fascia (deep surface turned outward); d, tendon. C. Diagrammatic cross-section of the tendon and transplanted fascia after the Lembert stitch has been drawn taut. Note that the smooth deep surface of the fascia adapted to the gliding function is turned outward: a, suture; b, fascia (superficial surface); c, fascia (deep surface); d, tendon.

or cannot be made to overlap. Under this condition I have found that the first suture method does not give sufficient security. Therefore, after uniting the tendons by means of the stitch, shown in Fig. 124, the suture is reinforced by trans-planting a piece of fascia from the calf. The technic of this procedure requires practice. A 3-inch incision is made, a

12

hands-breadth above the annular ligament of the ankle, and a strip of fascia 2 inches long and 1 inch wide is dissected away from the muscles. Particular care is taken to handle only the corners of the fascia, so as not to injure the loose fatty tissue (paratenon) which at this point covers the deep surface of the fascia and is of particular importance in facilitating the normal
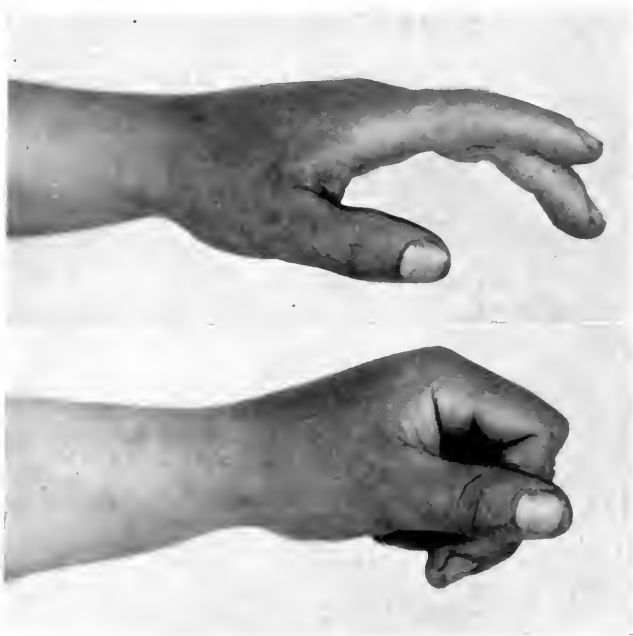
FIG. 125.—The degree of flexion secured by transferring the flexor sublimis tendon of the index finger for the severed flexor tendons of the middle finger; above, fingers extended; below, fingers flexed.

gliding mechanism of the muscles and tendons. At each corner of the fascial flap a suture is taken to permit more ready handling. The assistant grasps two of these sutures, the operator the other two, and in this way the fascia is transferred from the calf to the hand. The sutured tendons are then lifted out of their bed so as to pars two of these fixation sutures

beneath them.   By means of a continuous Lembert suture the
fascia is made to form a tube closely surrounding the sutured
tendons.   The fascia is so placed as to turn its glistening deep
surface outward, and if the Lembert suture has been properly
inserted the point of union of the two tendons is completely
hidden by a smooth strong envelope well adapted to a gliding
function.   The operation is concluded by continuous skin
sutures.
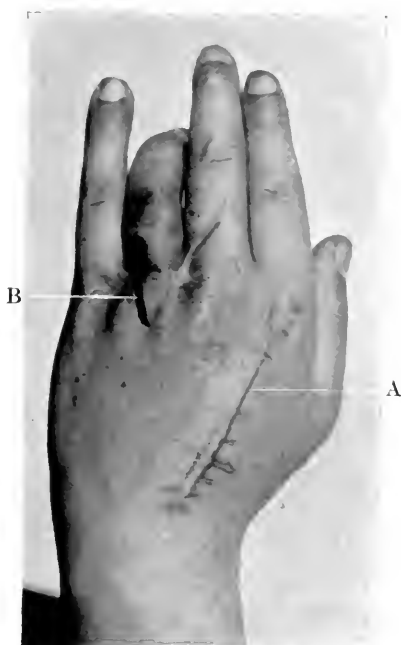
FIG. 126.—The incisions for transplantation of the index finger tendon of
the extensor communis digitorum to replace the severed extensor of the ring
finger.   A, Incision over the index finger tendon; B, convex incision over the
severed extensor tendon.

**A similar operation can be performed for the divided ex-
tensor tendon** provided the tendon of the extensor indicis
proprius has not been injured.   It consists in transplanting
the tendon of the extensor communis digitorum which runs

to the index-finger to replace the injured tendon.   The exten-
sor indicis proprius suffices, I have found, to extend the
index-finger.   A 4-inch incision lays bare the index-finger
tendon of the extensor communis digitorum (see Fig. 126).   A
second incision over the severed extensor tendon frees it from
the scar tissue which usually holds it adherent to the bone.
By means of a subcutaneous channel the substituting index
tendon is transferred to its new position and sutured to the
injured tendon by one of the methods above described.

After-treatment of Tendon Transplantations.—All tendon
transplantations require an immobilizing splint which holds
the extremity in such a position as to minimize the tension
on the transplanted tendon.   For this purpose the Jones
splints may be used, the plaster-of-Paris dressing, or, as I
prefer, the plaster-moulded splint.   The latter saves expense
and time, both in the application and in the removal.   The
duration of the immobilization depends upon the particular
operation: when a tendon can be implanted directly into the
bone, firm union has occurred, as determined by animal ex-
periment, secondary operations on human beings and clin-
ical experience, by the sixteenth day.   After that time, the
splint should be removed daily for active exercise of the
transplanted tendon.

When the tendon cannot be attached to the bone but is
sutured to another tendon, firm union does not occur as
quickly.   At least three weeks are required before healing has
occurred.   In the case of the operations for gunshot injuries
to the tendons of the hands, the after-treatment is particularly
difficult, since, by postponing exercise for three weeks, oppor-
tunity is given for the formation of adhesions to the scar tissue.
Therefore, even at the risk of tearing the tendons apart, it is
advisable to permit a little motion two weeks after the opera-
tion.   When proper caution is used by surgeon and patient,
the danger is slight.

In all cases, even after motion of the transplanted tendon is
allowed, it must be carefully protected until it has acquired
the strength of the normal.   Thus, for transplantations of the
tendons of the foot, a splint should be worn which holds the
parts in the overcorrected position: after transplantation of

the peroneus longus for paralytic flat-foot, an outside iron and Thomas shoe are used, after transplantation of the tibialis anticus for paralytic club-foot, an inner iron with a boot raised on the outer margin. Subsequent to operation on the hand corresponding splints, of metal or plaster, are readily devised to remove all strain from the transferred tendons.

Prognosis of Tendon Transplantation.—When a typical physiological operation can be performed, the operator should not be satisfied unless normal muscle balance is restored. In the presence of scar tissue, or if suture of tendon to tendon must be performed, the results are not as good. Then only about 60 to 70 per cent. of the normal range of motion can be expected.

Tenodesis.—Tenodesis or the fixation of tendons to bone is, particularly when combined with arthrodesis, an effective procedure in those cases to which tendon transplantations are not applicable. The following operations have given good results in my hands.

Tenodesis of the Extensor Tendons of the Index Finger Subsequent to Their Division.—The operation is indicated when, because of extensive scar tissue formation and infection, suture of the tendon is impossible. The interossei and lumbricals suffice to extend the distal phalanges, but the flexion of the proximal phalanx prevents effective use of the finger. By immobilizing it in the extended position the patient is enabled to use the finger for all forms of fine manual work.

Technic.—A 1½-inch longitudinal incision exposes the extensor tendons as they pass over the metacarpophalangeal joint. They are freed from the surrounding tissue, divided ½ inch proximal to the joint and retracted downward so as to expose the joint. It is then denuded of cartilage with an appropriately shaped gouge. The proximal phalanx is held in the extended position and the extensor tendons firmly sutured to the traumatized periosteum and the metacarpal bone. In case it is impossible to secure firm mechanical fixation by these means, a small hole is drilled in the metacarpal bone and the tendons brought through this.

Subsequent to the operation the finger should be immobilized for three weeks and for two months thereafter a small

splint should be worn, holding the proximal phalanx in the extended position.

Tenodesis of the Extensor Tendons of the Wrist.—This is applicable to gunshot injuries in which there has been very extensive loss of substance of all the muscles of the extensor surface of the forearm, with scar tissue formation extending down to the wrist, precluding the possibility of effective tendon transplantations.

Technic.—Two 1½-inch longitudinal incisions, extending from the annular ligament upward, are made, the first over the extensor carpi radialis (longior and brevior), the second over the extensor carpi ulnaris. The tendons are freed, divided about 1 inch above the wrist and, with the hand in the hyperextended position, the tendons are drawn through holes drilled in the radius and ulna. The fixation must have sufficient mechanical security to hold the hand in the desired position. Splint for three weeks with the hand hyperextended, and for two months thereafter guard against flexion by a slight support which gives the fingers free play.

Tenodesis of the Extensor Tendons of the Foot in Cases of Footdrop Due to Paralysis of the External Popliteal Nerve.—Although I have had no experience with this operation the authority of Sir Robert Jones is sufficient to recommend it. For the technic the reader is referred to his "Notes on Military Orthopedics," page 23.

In cases of complete paralysis of the foot, I have employed tenodesis with excellent effect *in conjunction with arthrodesis.* All three extensor tendons are freed and drawn through channels bored through the crest of the tibia. The extensor longus digitorum and peroneus tertius are pulled very taut, so as to prevent the adduction of the anterior portion of the foot which so frequently follows arthrodesis.

In performing the arthrodesis two methods may be pursued.

1. Through two small lateral incisions on either side of the ankle joint, exposing the superior and the inferior surface of the astragalus, from which the cartilage is scraped with a sharp curette or with a gouge.

2. By the Albee method of enucleating the astragalus, denuding it of its cartilage and reinserting it.

Tenodesis of the Achilles Tendon for Paralysis of the Gastrocnemius and Soleus.—With this operation also I have had no personal experience, since I have preferred transplanting the flexor longus pollicis and peroneus longus tendons as substitutes for the paralyzed. Gallie, however, has been able to achieve excellent results by this method, so that it certainly should be considered as an important operative procedure. As in the previous tenodeses, the tendon should be implanted directly into the bone with sufficient tension to hold the foot in the corrected position. For further details the reader is referred to Dr. Gallie's description in the *American Journal of Orthopedic Surgery*, vol. xiv.

CHAPTER X

TREATMENT OF THE AMPUTATED

In the first portion of this book, no mention was made of amputations performed at the front since these are strictly surgical in nature. The usual operation is a simple oval or circular amputation, executed as rapidly as possible, with little thought of any result other than saving the patient's life. When these patients with a limb already amputated reach the base hospital, their further treatment should fall into the hands of some one versed not merely in surgical technic but in orthopedic principles and, above all, in the application of artificial limbs. The practice of turning the patient over to the manufacturer of artificial limbs as soon as the amputation wound has healed, is frequently responsible for much unnecessary suffering and many instances of poor function. Only by a rational harmonizing of surgical technic and orthopedic treatment with the brace-maker's art, can satisfactory results be achieved.

Preliminary Treatment of the Stump.—*When the Amputation Wound is Still Unhealed.*—It frequently occurs that by the time the patient has reached the base hospital the loose sutures applied at the time of the primary amputation have torn out, the skin flaps have retracted, and a large granulating area lies exposed. Attempt must be made to prevent further retraction of the skin. This is best done by applying a piece of stockinette to the stump after first painting it with some adhesive mixture, such as a solution of mastic.[1] The free ends of the stockinette projecting below the stump are gathered

[1] The solution of mastic is made as follows:

    ℞. Mastic............................... 20;
       Chloroform......................... 50;
       Linseed oil .... gtt. xx.

together by a stout cord, which, passing over a pulley, serves for the attachment of a suitable weight, (3 to 10 pounds). To bandage the wound, the cord is loosened and the edges of the stockinette turned backward so as to expose the granulating area. In many cases where the skin has not already become adherent, this method suffices to coapt the skin edges; when much retraction has already taken place and the skin has become adherent to the deeper structures, it merely prevents further retraction.

Postural Treatment.—Care must be taken to prevent the development of contractures. The most frequent mistake is in the case of patients with amputations of the thigh or of the calf. The nurse, in her effort to make the patient comfortable, places a pillow beneath the stump, thus flexing the thigh at the hip or flexing the knee. This error, usually unnoticed at the time, results in flexion contractures whose significance is not appreciated until the first fitting of the artificial limb. Then the brace-maker tells the surgeon that something is wrong, and that he cannot make the artificial limb fit correctly. As a consequence months of treatment are required to lengthen the contracted tissues until the free range of motion has again been acquired.

The same principle emphasized in the treatment of injuries to the muscles should be applied to the amputated; the position of the limb should be such as to prevent the overaction of the strong muscles at the expense of the weaker. Thus, at the hip and at the knee, every effort must be made to prevent the strong flexors from overcoming the action of their weaker antagonists. At the shoulder, the strong adductors must not be allowed to contract at the expense of the abductors. The application of the principle is simple. In the case of a patient with thigh amputation, a small pillow is placed under the buttocks so as to allow the thigh by its own weight to fall into the position of slight hyper-extension. For the amputation of the calf, a pillow is placed not in the popliteal space, as is so frequently done, but near the end of the stump, so as to promote the full degree of extension. For amputations of the arm, a small pillow is placed between the chest and the limb, so as to promote abduction. For amputations

of the lower arm, the limb is simply allowed to lie in the fully extended position.

The one exception to this rule is in the case of amputation just below the knee, where the stump is so short that there is no possibility of affixing the artificial limb to the calf. In this event, it is particularly difficult to keep the short segment of the calf extended and as the artificial limb is constructed so as to permit the patient to walk about with the stump flexed, there is no advantage gained in attempting to maintain the extended position.

Re-amputation.—The surgeon should not be too hasty in deciding that re-amputation is necessary. I well recall two instances in which despite the discouraging appearance of the stump, which led me to prepare the patient for operative revision, I was able within several weeks' time to secure excellent results by non-operative procedures. The extension method for exerting traction on the skin has already been described; in addition to this, every effort is made to encourage epithelialization. The presence of scar tissue over the end of the stump does not necessarily mean a poor stump, although it is, of course, preferable to have a normal skin covering.

The indications for re-amputation are: (1) projection of the bone beyond the granulation tissue; (2) persistent ulceration of the stump owing to the thinness of the epithelial covering; (3) a fixed contraction of a short stump in such a position as to render application of the artificial limb impossible; (4) in rare instances for painful neuromata which yield to no other form of treatment. A conical stump is in itself no indication for re-amputation since it may, if properly exercised, develop excellent functional capacity.

A discharging sinus, due to the presence of a sequestrum or foreign body, necessitates operative removal (easily accomplished through a small incision) but this operation is in no way analogous to a re-amputation.

Whenever possible, re-amputation should be avoided, since it invariably necessitates shortening the stump. This means loss of power, since the longer the stump, the more accurate its coaptation to the artificial limb and the more effective its

action. Of course, if the stump be a long one, with the site of the amputation just above the ankle or the knee, a few inches can be sacrificed without appreciable diminution of power.

The principle of maintaining the maximum length of the stump disagrees with the practice of many eminent surgeons, and therefore deserves further consideration. Thus, it is maintained by Riedel, who himself suffered amputation below the knee-joint, that the stump of the calf, although amply sufficient for the attachment of the artificial limb, was a useless encumbrance. After one year's trial, he insisted upon a re-amputation at the knee, using the Gritti method, and professed himself far happier with the short stump than with the longer. My experience has led me to the opposite conclusion. Except in those rare instances already referred to, where the stump of the calf is so short as to make it impossible to grip it in the socket of the artificial limb, every patient whom I treated found it of great advantage to be able to control the prosthesis by the action of the intact quadriceps extensor muscle. Whether the stump was suitable for weight-bearing or not, made far less difference than the additional security given by the voluntary control of the knee-joint. The longer the stump of the calf, the longer the leverage arm controlled by the patient, and the easier for the brace-maker to secure an accurate fit. This is made clear if one thinks of the stump as the piston of an air-pump. Just as the security of the piston is most marked when it is pressed downward its full length into the air-pump, so too, the stability of the stump within the artificial limb is greatest when there is the largest area of contact between it and the prosthesis.

The same holds good for amputations of the thigh, where in the case of the short stump, it is exceedingly difficult for the patient to manipulate the apparatus; whereas, with the long stump, almost the normal stride can be attained. With the upper and lower arm, the effectiveness of the stump for practical purposes is in proportion to its length; and in the case of wounds shortly below the elbow, everything should be done to preserve a stump of the forearm, however short that may be.

In applying the rule relative to the maximum length of the

stump, the surgeon must beware of ultraconservatism. Thus, for instance, when an amputation at the ankle is indicated, it would be unwise to leave the astragalus attached to the stump, since in the first place, this bone would render the stump too long for the proper application of the prosthesis; in the second place it would not be as well suited to weight-bearing as an osteoplastic stump. George Marks recites an instance of amputation through the mid-calf in the case of a patient whose knee-joint had already been ankylosed. Naturally this ultraconservatism made the normal application of the prosthesis impossible, and the patient had to go about with one thigh apparently 6 inches longer than the other.

The principle of maintaining the maximum length of the limb does not belittle the importance of securing, whenever possible, a weight-bearing stump. If the stump can be rendered capable of supporting the body, the problem of fixing the artificial limb is rendered much simpler. To this end, certain osteoplastic operations are of great value and should be performed wherever feasible. In a class by themselves stand the Pirogoff and Gritti amputations. Both these procedures are excellent examples of the physiological method, and when properly executed invariably give good results.

Of course, an important condition for the success of all the osteoplastic operations is an absolutely aseptic field. When this cannot be had, the operations are contraindicated.

In the calf, when the stump is a long one, so that several inches may be sacrificed with comparatively little loss of power, the Bier osteoplastic method usually results in a weight-bearing stump. When this operation is not feasible, it matters little whether the so-called "aperiosteal" technic is followed, or whether the periosteum is left adherent to the stump. Irrespective of the treatment of the periosteum, it will be found that in some cases bony spurs develop, and in others they do not. In all cases of amputation of the calf, the fibula should be divided at least ½ inch above the level of the tibia.

I have found the following technic to give good results in cases where the Bier osteoplastic method is contraindicated. The skin flaps are so planned that the anterior is large enough

to cover the inferior surface of the stump. The muscle flap, on the contrary, is taken from the posterior aspect of the calf, since the fleshy gastrocnemius and soleus furnish the best covering for the inferior surface of the tibia. The muscles are attached to the periosteum by strong sutures anterior to the weight-bearing surface; as the skin suture lies posterior, there is no suture line subjected to pressure when the artificial limb is applied.

In amputations of the thigh, where the Gritti is not applicable, the Bier method can be followed provided the stump is sufficiently long.

If the stump be short, as little tissue should be sacrificed as possible. An elliptical incision is made, and a cone of granulation tissue and muscle—with its apex at the bone—is excised, the bone sawed off at this level, and the parts drawn together by strong, coapting sutures.

In patients with a femoral stump, not more than 2 or 3 inches long, the presence of an abduction or flexion contracture renders the application of the artificial limb impossible. The problem in these cases is solved most simply by disarticulation of the femur at the hip. Nothing is lost, since the stump is too short to control the artificial limb, and much is gained in the ease of application.

For amputations of the upper limb, the question of weight-bearing plays no rôle whatever. The stump should invariably be left as long as possible, and re-amputation performed only when there is urgent indication.

Kinetic Stumps.—Vanghetti and later Ceci attempted the utilization of the latent muscular force of the stump by freeing the tendons or muscle bellies in such a way as to enclose them with skin flaps. These flaps could then be moved by the voluntary muscular contraction of the patient's stump. During the last 3 years the method has been modified by Sauerbruch (until recently professor of surgery at the University of Zurich) and the technic so developed that it can be regarded as a perfected surgical procedure. Figs. 127 *et seq.* illustrate the steps of the operation. Instead of the original Vanghetti technic a much simpler method has been adopted. After freeing a skin flap of appropriate size (Fig. 127) a

tunnel is bored through the muscle belly (in this instance the biceps) and widened sufficiently to admit the skin flap which has been sutured to form an epithelial lined tube (Fig. 128). A simple skin plastic completes the operation (Figs. 129 and 130). The canal is kept patent by means of a rubber drainage tube or ivory peg, and as soon as possible active exercise of the muscle (see Fig. 130) begun.
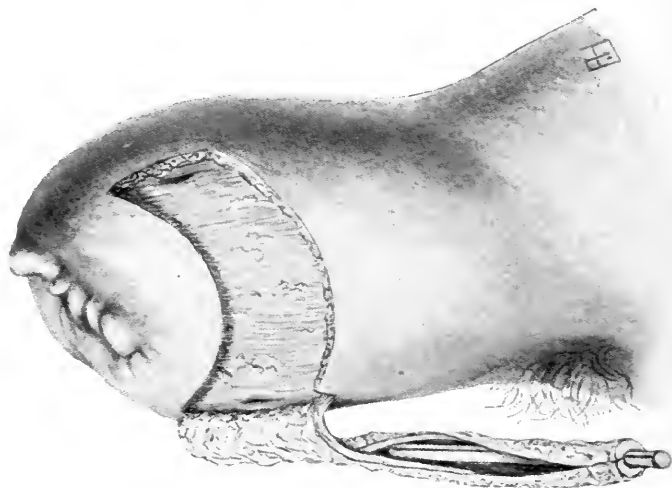
Fig. 127.—The Sauerbruch method of producing a kinetic stump. First step of operation. A tunnel has been bored through the biceps muscle. A skin flap has been freed and is being sewed about a piece of rubber tubing with the epithelial surface turned inward.

Excellent though the operative results are, the practical benefit to the patient has thus far been slight, owing to the difficulty in constructing a prosthesis capable of utilizing the muscular force placed at its disposal. If this mechanical problem can be solved, the Sauerbruch procedure will constitute an important advance in our methods of treating the amputated.

Although Sauerbruch has, so far as I know, confined his operations to the upper extremity, its field of usefulness might well be extended to amputations of the thigh. Here voluntary control of the artificial limb by means of the quadri-

ceps extensor, would be of great assistance to the patient,
particularly to one whose work called for walking over uneven
ground, hill climbing, and ascending or descending steps.

The Education of the Stump.—Even before the wound has
healed, the physician must begin treating the stump with a
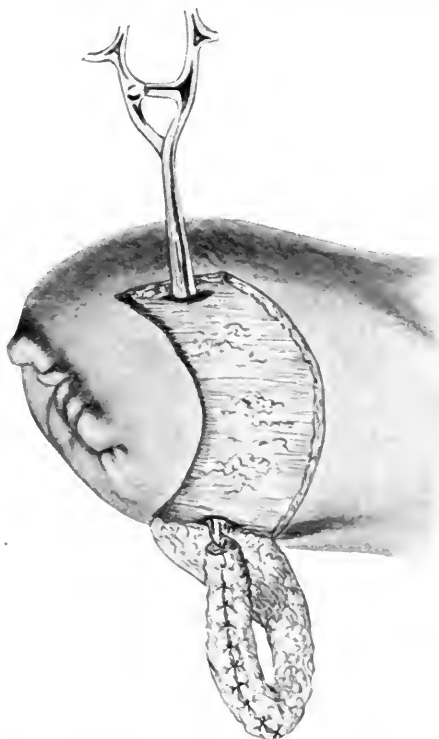
Fig. 128.—The Sauerbruch method of producing a kinetic stump. Second
step of operation. The epithelial-lined tube is being drawn through the
channel in the muscle.

view to developing its function. The muscles should be
massaged and the patient should be encouraged to move the
limb. As soon as the wound has healed, more vigorous meas-
ures can be adopted. The stump should then be bathed daily
with cold water, and in addition to the massage, graduated
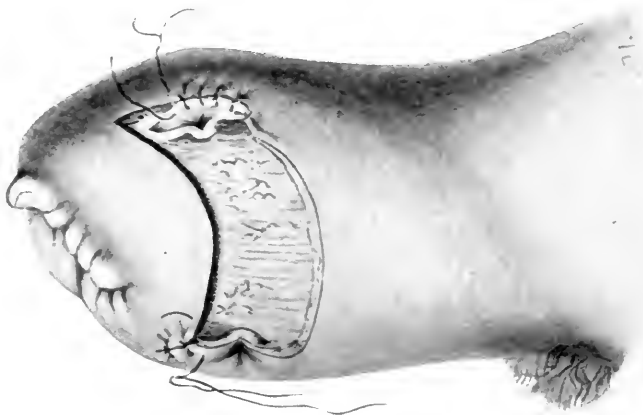
Fig. 129.—The Sauerbruch method of producing a kinetic stump.   Third step of the operation.   The sutures are being taken to unite the edges of the skin flap to the skin of the arm near the point of emergence from the muscular channel.
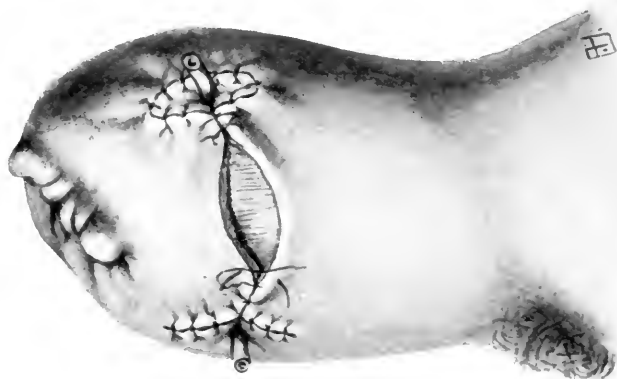
Fig. 130.—The Sauerbruch method of producing a kinetic stump.   Fourth step of operation.   The operation is completed by uniting the skin edges as shown in the illustration.   The canal is kept patent by running a piece of rubber tubing or an ivory peg through it.

exercises should be performed. These consist of simple movements—flexion, extension, abduction, adduction and rotation—against the resistance of a weight running over a pulley, or of the hand of a trained masseur. Bandaging the stump firmly helps remove fat and reduce the œdema. To
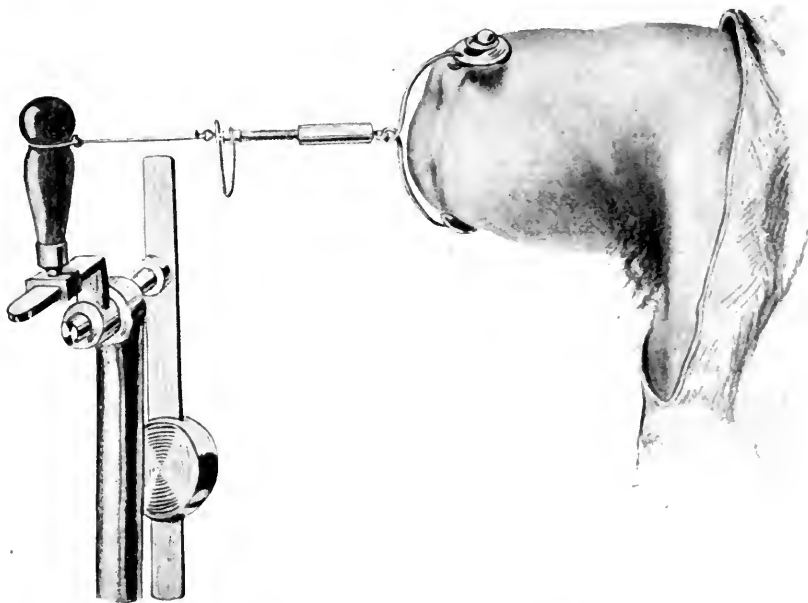
Fig. 131.—The Sauerbruch method of producing a kinetic stump. The after-treatment. To exercise the muscle through which the channel has been bored, the ivory peg running through it is attached to a pendulum apparatus. The patient can by a voluntary contraction of the muscle cause the ivory peg to move upward and thus move the lever of the apparatus. By regulating the length of the pendulum the exercises can be graduated to meet the increasing muscular power of the patient.

assist in the hardening process, leading to weight-bearing function, the patient should learn to rest the end of the stump against a chair or stool of suitable height. At first the chair is thickly padded; gradually the padding is removed, until the patient is able to bear his weight on the bare wood. He then begins to hammer with the end of the stump against the

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support, since a certain amount of this pounding motion is incidental to walking with the artificial limb.   This treatment should, of course, be carefully graduated, otherwise the stump tends to become irritated instead of hardened.

Some authors have laid great emphasis on forming a deep circular furrow in the stump.   This furrow serves for the attachment of the socket of the artificial limb, and does in some instances undoubtedly add to the stability of the prosthesis.   I have found that with rare exceptions, however, the method is not of particular value.   The exception consists of those instances of short stumps of the calf (about 3 inches long) which it is difficult to grasp firmly with the artificial limb.   In these cases, a furrow is of distinct assistance.   The Esmarch bandage, or better still, a strong piece of rubber tubing about $3/8$ inch in diameter, is applied to the stump under as much pressure as the patient can stand, and kept in place for an increasing length of time with each application. After several days the patient is usually able to stand the pressure for several hours.   Within two weeks, a distinct furrow can be developed.

The greatest educator of the stump is the artificial limb itself. Therefore, it should be applied as soon as possible.   The use of a crutch for the amputated is an indication of inadequate treatment.   The early use of an artificial limb presents one great difficulty: the stump is still swollen, a large amount of fatty tissue is still present, and the muscles are usually flabby. With time, the stump changes its shape so markedly that the artificial limb, which fitted accurately when first applied, is no longer suitable.   If this has been made of leather or wood, great expense has been involved, and the value of early training of the stump seems to be outbalanced by the economic waste of time and material involved in the construction of an artificial limb whose period of usefulness is so short-lived. Owing to this difficulty, the provisional or temporary prosthesis has been evolved.   The evolution of these provisional limbs has been most interesting.   At first they were constructed in the crudest way of a broom-stick or a piece of bamboo incorporated in a plaster shell fitting the patient's stump (see Fig. 132).   Later, an iron framework was substituted for the

broom-stick, terminating in a flat metal plate which could be rivetted into the empty shoe of the patient. A still later development was the use of a hinged joint corresponding to the knee (see Fig. 133), in cases of amputation of the thigh, so that the patient could learn early to utilize the joint of the

Fig. 132.—A simple type of provisional artificial limb, consisting of a broom stick incorporated into the plaster dressing which envelops the stump.

artificial limb instead of striding with a stiff leg. All of these contrivances served their purpose in helping to educate the stump and in teaching the patient how to walk.

To Mommsen belongs the credit of evolving what is, in my experience, the most practical and efficient provisional artificial

limb. Assume that the patient has been amputated six inches below the knee. An exact plaster impression is taken of the stump by enveloping it with a plaster-of-Paris bandage. The plaster should not be thicker than $\frac{1}{16}$ inch. While it is hardening, the operator should carefully mould the tuberosity
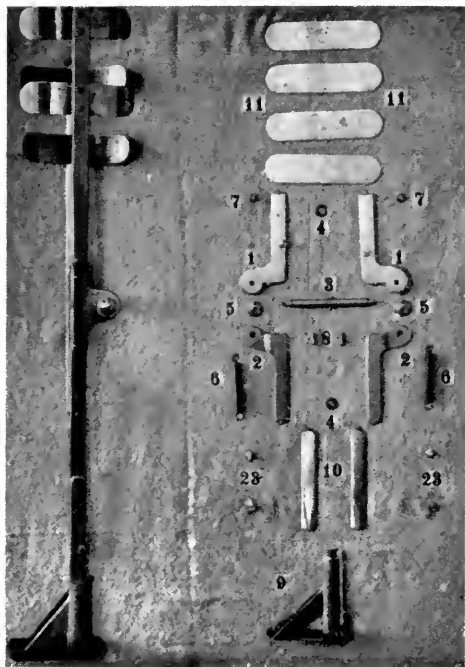
Fig. 133.—A provisional artificial limb (Spitzy) with movable knee joint. The transverse pieces marked 11 are easily bent, so that they conform to the curve of the thigh and are easily attached to the plaster dressing which encircles the stump. The foot piece is rivetted to the patient's boot.

of the tibia (see Fig. 134), since this bony projection forms the chief weight-bearing area. The head of the fibula and the condyles of the tibia are not subjected to pressure, since experience has shown that they are not adapted to weight-

bearing. The plaster negative is then turned over to the brace-maker, who makes the corresponding foot, steel supports, knee-joint, and thigh-piece, just as though he were making an artificial limb for a patient whose stump had assumed its final definite form. The one difference between the final

Fig. 134—Making a provisional artificial limb for an amputation of the calf. (*Mommsen*.) The figure illustrates the first step in the process when the exact plaster impression is taken of the patient's stump. Note that the surgeon is bringing pressure to bear on each side of the tuberosity of the tibia. The condyles and the head of the fibula should not be exposed to pressure.

prosthesis and this provisional one, lies in the fact that the plaster shell has been substituted for the usual leather socket (see Fig. 135). The steel uprights are firmly fixed to the plaster by means of two rivets, and a series of bandages soaked in a

mixture of plaster-of-Paris and bone glue (see footnote).[1]   In other words, the patient is given at once the same type of artificial limb which he is to wear after the stump has attained its constant shape.   During the stump's transition period, the

Fig. 135.—The provisional artificial limb for an amputation of the calf. It is exactly like the finished prosthesis, except that the socket into which the stump fits is of plaster-of-Paris instead of leather.

plaster negative can be changed whenever necessary, since the cost is minimal and the labor involved comparatively slight.

[1] This mixture, which though light is extremely hard, is prepared as follows: 400 grams of bone glue, broken into small chips, are dissolved in half a liter of water, heated over a water-bath.   When boiling, 400 grams of alabaster plaster-of-Paris in the form of a thin plaster cream are added slowly to the glue.   The mixture is constantly stirred during the process, and the preparation kept as near 100°C. as possible.   When thoroughly mixed and boiled, the requisite number of starched bandages of appropriate width are immersed in the fluid, and when saturated are wound about the plaster shell, so as to strengthen it and hold the steel upright of the artificial limb firmly in place.   Complete by a few turns of a plain gauze bandage.   Dry in a warm room one to two days.

For amputations of the thigh, the technic is similar.   In these cases, the surgeon must lay stress upon an accurate moulding of the tuberosity of the ischium, since this bone is to bear the weight of the patient's body (see Fig. 136).

When the stump has, after many months, assumed a form which no longer changes, then leather is substituted for the plaster-of-Paris, and the patient is equipped with a finished prosthesis.

Fig. 136.—Making the provisional artificial limb for an amputation of the thigh.   (*Mommsen.*) An exact plaster impression is taken of the stump.   The surgeon's fist brings pressure to bear just below the tuberosity of the ischium, so as to mold the support for the weight of the body.

Types of Artificial Limbs for the Lower Extremities.— It would far exceed the limits of this book were even mention to be made of the hundreds of different varieties of artificial limbs designed for amputations of the lower extremities which have been devised during preceding centuries, or which are now on the market.   Study of about fifty different specimens has impressed me with certain conclusions which are, I think, of greater importance than the details of each particular invention.

1. *For amputations of the thigh,* it is important to distinguish between those stumps which are weight-bearing and those which are not. In the latter case, the success or failure of the artificial limb depends upon an accurate fit at the ischial tuberosity. Most brace-makers fail to realize that the tuberosity does not slant from above downward and forward but in the reverse direction, namely, from below upward and forward. This upward inclination, be it ever so slight, must be taken into account. The usual type of support given by the brace-maker, does not conform to this anatomical fact, but slants from above downward and forward, so that the patient slips downward on the support and almost invariably suffers pain anteriorly, near the pubic bone. The result is that the stump is rotated, and the artificial limb does not fit.

In addition to the tuberosity of the ischium, the adductor muscles are capable of bearing great weight when they have been properly hardened. The pubic bone, however, cannot stand pressure and must be left free. The gluteal muscles and the vasti also help to support the body-weight.

When the stump is short, a pelvic girdle with a strong joint at the level of the trochanter is necessary; whereas in the long stumps, the pelvic band and trochanteric joint are unnecessary. In patients with marked atrophy of the muscles, unable to balance themselves securely upon their stump, the trochanter joint should allow flexion and extension only, since the pelvis would drop toward the opposite side of the body, were abduction permitted.

In applying the steel uprights which support the body, or, in case of a wooden limb, in joining the thigh-piece with the calf, it is advisable to give the calf about 2° of genu valgum position. This adds markedly to the stability of the artificial limb.

The type of knee-joint does not, so far as I can observe, play an important rôle. In general, the simpler the mechanism the more effective. Complicated screws, ratchets, or springs add merely to the likelihood of breakage and to the cost of keeping the limb in order. Besides, for the majority of patients, who live at a distance from the industrial centres where brace-makers are to be found, the entire construction

of the limb should be so simple as to permit the wearer himself to make the necessary repairs. In one European hospital there is an admirable custom of giving each amputated patient a 3 weeks' course in the brace-maker's shop, and discharge from the hospital is dependent upon ability to repair his own prosthesis.

An essential in the mechanical construction of the joint is the location of its axis posterior to the centre of gravity of the
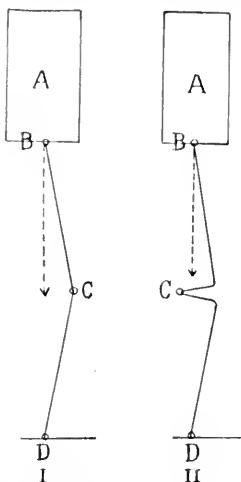
Fig. 137.—Diagrams illustrating the importance of posterior displacement of the knee joint of the artificial limb. A, Body; B, hip; C, knee joint; D, ankle. In Fig. I, the axis of the artificial joint corresponds in position to the anatomical. A slight degree of flexion brings the body weight posterior to the axis and, as is evident from the figure, further flexion must result. For the patient this position of the axis causes insecurity since the least degree of flexion is almost certain to cause him to fall. In Fig. II, the axis of the artificial limb has been displaced posteriorly. The body weight, represented by the dotted line, now falls anterior to C (the axis) and tends to lock the knee instead of producing further flexion.

anatomical joint. If this demand is not complied with, the patient loses all sense of security, because the artificial leg tends to bend at the knee under the patient's weight. If the mechanical joint lies posterior to the normal, then the body-weight tends to lock the joint as is seen by reference to the diagram (Fig. 137).

An artificial quadriceps does not, I find, add to the natural-
ness of the stride, but almost invariably tends to hold the leg
fully extended, so that the patient walks as though the knee
were ankylosed. A freely swinging joint with some simple
rubber or spring device to prevent jarring in extension or
flexion gives the patient the best opportunity to imitate the
normal gait.

2. *For amputations of the calf*, the type of limb depends
upon the length of the stump. If it is short—less than one-
half the length of the calf—there must invariably be a thigh-
piece and a knee-joint. If it is long, these may be dispensed
with provided the stump is capable of weight-bearing.

As already indicated, when the stump is not capable of
weight-bearing, the artificial limb must be so moulded as
to grasp the tuberosity of the tibia firmly, not the condyles,
as is usually taught. The patella-tendon also is capable of
weight-bearing, as can be learned by observing any patient
who has worn an artificial limb for many years.

Some difficulty is frequently experienced in bringing the
leather socket of the artificial limb over the gastrocnemeii.
This can be obviated by slitting the socket posteriorly and
inserting eyes so as to lace it up when once it is in proper
position.

The ankle-joint, like the knee, should be of the simplest
type, allowing merely flexion and extension. In addition to
the ankle-joint, there should be one corresponding to the
metatarsophalangeal junction.

**Types of Artificial Limb for Amputations of the Upper
Extremity.**—The problem of dealing with amputations of the
upper extremity is far more difficult than is the case with
amputations of the lower limbs. The legs merely have to
carry the body, but the arm has a great variety of functions
to perform. Depending upon the nature of these functions,
and also to a great extent upon the site of the amputation, the
artificial limb must vary from one case to another. Thus,
an artificial limb which might be of value to a lawyer or busi-
ness man would be of little use to the farmer or mechanic;
and of two farmers, one with an amputation of the forearm,
another with an amputation above the elbow, the one would

have to be equipped with a type of limb differing markedly from that supplied to the other. There is no universal artificial limb applicable to all cases.

1. *Types of Artificial Arms Designed for Amputations of the Fore-arm.*—For the farmer and artisan, a simple and effective prosthesis has been designed by August Keller. Amputated

Fig. 138.—The Keller artificial hand. The picture illustrates Keller's method of inserting a small knife, with which he is sharpening his pencil. Note also the piece of cork attached to the pencil. This enables him to grip the pencil between the claws and to write with it. The lower arm socket is held firmly in place by a broad strap which makes a figure-of-eight turn about the elbow.

himself, some nine years ago, he constructed an artificial limb of the simplest materials, so well adapted to the needs of the farmer that the amputated scarcely note the handicap under which they are compelled to work. Keller's device consists of a leather socket reinforced by two longitudinal steel bars, held in place by a figure-of-eight strap which passes just above

the elbow (Fig. 138). The hand-piece, made of wood, can be removed from the socket if desired (Fig. 141). Inserted into the wooden hand-piece are three strong steel hooks. These are not adjustable. They aid the patient in two ways: first, small objects, such as pencil or knife, can be inserted between them, second, they furnish the leverage for larger instruments. To hold these latter in place, a leather strap, attached to the

FIG. 139.—The Keller artificial hand. Keller at work with his spade.

anterior portion of the apparatus, is made to take a double turn about the handle of the article used (see Fig. 143) and then passing backward between the hooks, is fixed to the posterior aspect by means of a steel pin. The illustrations indicate how Keller uses his own device. The speed, accuracy and power which he exhibits are scarcely inferior to that of the normal individual.

A large number of other contrivances have been evolved to replace the fingers. These consist of hooks, rings, clamps, and

holders designed for special articles, such as knife, fork, spoon, pen or pencil, knitting needle, etc. Some of these are shown in Figs. 144, 145, 146 and 147. Several excellent devices have been invented by Judge Corley, of Dallas, Texas. One of these, a most ingenious arrangement enabling the wearer to button his own collar, is illustrated in Fig. 148.

For the business man, or the professional, a more suitable type is the arm designed by Carnes. In this, the mechanism

Fig. 140—The Keller artificial hand. Keller pruning a small tree.

is far more complicated, and the cost therefore proportionately greater. Despite the delicate mechanism, however, it is capable of standing the usual amount of wear and tear, and a break of any constituent part can readily be replaced. The essential feature of the arm is the voluntary control of motion of the fingers and of the wrist by means of bands which become shortened or lengthened by motion of the elbow-joint. The arm requires considerable practice before the technic of

its use can be acquired.   To give a patient such an artificial
limb and expect him to be able to use it at once, is as illogical
as presenting a man with a violin and telling him to play upon
it.   When, however, its use has been mastered, it gives sur-
prisingly good results.

The mode of attachment of the artificial limb to the stump is
of importance.   The hinge-joint at the elbow with an upper

Fig. 141.—The Keller artificial hand.   The hand attachment can be
removed, permitting the insertion of various instruments.   In this instance
a hammer has been inserted, which Keller is able to use with the same dex-
terity as a normal individual.

arm cuff, the usual type found in the brace-maker's shop
should not be employed, since it gives no opportunity for pro-
and supination.   A simpler and far more advantageous
method of attachment is the figure-of-eight strap, which passes
just above the condyles of the humerus and crossing the poste-
rior surface of the humerus descends again over the anterior
surface (see Fig. 138).

2. *Types of Arm Designed for Disarticulation of the Elbow
or Amputations of the Upper Arm.*—The classical type of limb
is a useless encumbrance and is almost always relegated to the

garret by the intelligent patient.   To be of any assistance to
its wearer, the prosthesis must, even more than in the case of
that for the forearm amputation, be particularly designed for
the special work to be performed.   Fig. 149 shows a fourteen-
year-old patient to whom belongs the credit of evolving a prac-

FIG. 142.—The Keller artificial hand.   For aesthetic purposes Keller draws
a glove over the hooks.   This he terms his "Sunday" hand.

tical working arm for disarticulation at the elbow.   When
this lad was placed in the carpenter shop, I suggested that he
construct an artificial limb to help him at his work.   I ex-
pected to see the usual hinge-joint at the elbow, prolonged
downward to serve for the attachment of a hook or a clamp.
To my great surprise, after a few days the lad showed me the

artificial limb pictured in Fig. 150. It will be noted that
instead of a hinge-joint, there is a ball-and-socket joint at the

Fig. 143.—Keller splitting wood. Note the double turn of the leather
strap around the handle of the axe. This gave Keller so strong a grip on the
handle that the united strength of three men was unable to pull the axe away.
Keller's dexterity equalled that of an expert woodsman.

Fig. 144.—The Fischer clamp for the use of the one-armed. The three
prongs facilitate holding objects obliquely as well as in the axis of the limb.

elbow, which, according to the patient's statement, he had
constructed because he wished not merely to bend at the elbow

but also to turn the forearm.   In other words, he had solved
a problem which makers of artificial limbs had for centuries

FIG. 145.—Clamp and hook serviceable for the amputated workman.
The clamp serves to hold a file, brush, small hammer, etc.   The hook can be
used to carry a pail or to lift heavy objects.

FIG. 146.—A professional pianist, whose right hand had to be amputated
because of gunshot injury.   Equipped with a special device of Hoeftemann's,
he was able to continue his profession.   It was possible for him to strike
single notes and chords with facility.

failed to answer; namely, the best method of combining flexion
and extension with pro- and supination.   Between the con-

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cave extremities of the upper and lower arm pieces was in-
serted a wooden sphere, bound to the adjacent concavities by
a strong spring.   The friction between the opposing surfaces
was sufficient to lock the arm at any desired angle.   With

Fig. 147.—Hoeftemann's device for the professional pianist shown in Fig. 146.

Fig. 148.—Judge Corley's apparatus for helping the man who has lost both
hands to button his own collar.

the aid of this simple device, the patient within two years
became an expert carpenter and, entirely unassisted, was able
to do the finest kind of cabinet work.   Of course it must be
remembered that the artificial hand plays the rôle of assistant
to the sound arm, and the success of the patient in becoming an

expert artisan was due in large part to the fact that the major work done by the carpenter is performed by one hand aided to a comparatively slight degree by the other.

FIG. 149.—A 14-year old carpenter's apprentice amputated at the elbow, showing the artificial limb which he himself designed. By inserting a wooden sphere between the concave extremities of the upper and lower arm pieces he could not only flex and extend but supinate and pronate.

Another valuable type of arm is illustrated in Fig. 152. This device is purely for working purposes, and must be supplemented by another arm which hides the defect. It consists of a broad padded metal ring which fits over the shoulder and is held firmly in place by straps passing around the body. To

this ring is attached a second, which, running on ball bearings, has perfect freedom of rotation on the first ring. To the second are attached steel uprights which run parallel with the stump and terminate at the level of the elbow in a circular disc to which various instruments useful to the carpenter can be

Fig. 150.—The carpenter's apprentice shown in Fig. 149 guiding the plane with his artificial arm.

attached. The stump is bound firmly to the steel uprights by means of straps, and owing to the ball-bearing joint at the shoulder the wearer has almost the normal range of motion. A little ingenuity in devising the tools to be inserted into the disc enables the amputated to do even the most delicate kind of carpentry work. One tool suffices to grasp the screw of the

screw-and-bit; another grasps the nail so that the uninjured hand is free to hammer; another is designed to hold the chisel, etc.

An interesting modification of the working arm suitable for amputations above the elbow, is the utilization of a spring at

FIG. 151.—The carpenter's apprentice already pictured in the preceding figures, at work with the saw. The artificial limb is used to steady the board.

the elbow-joint, which permits a springy motion of distinct value in hammering, filing, etc., work in which absolute fixation at the elbow takes away from the freedom of the stroke. Fig. 154 illucidates the principle of this arm. By fastening screws A and B, the arm can be absolutely fixed at any desired

Fig. 152.—The Siemens-Schuckert arm for amputations above the elbow.
For descriptive text see page 209 *et seq.*
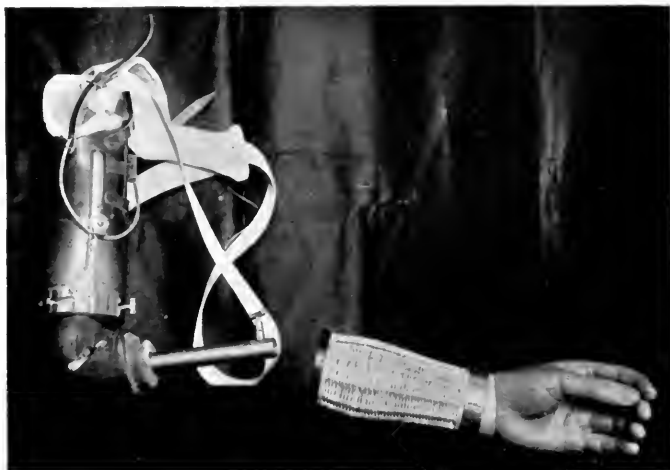
Fig. 153.—The Biesalski artificial arm for amputations above the elbow.
(First model.) This arm was probably the first in which an elbow joint was
constructed corresponding to the anatomy of the normal, and the first in
which a working arm was combined with an æsthetic means of hiding the
defect. The lower arm portion consists of a strong metal tube, into which
working implements can be inserted and over which the artificial hand can
be placed, when the wearer is through with his day's work.

angle. By releasing screw A which controls the springs, the plunger is allowed to move backward and forward, allowing about 10° motion, but not beyond the limit set by the screw B. Pronation and supination are not possible in this type of
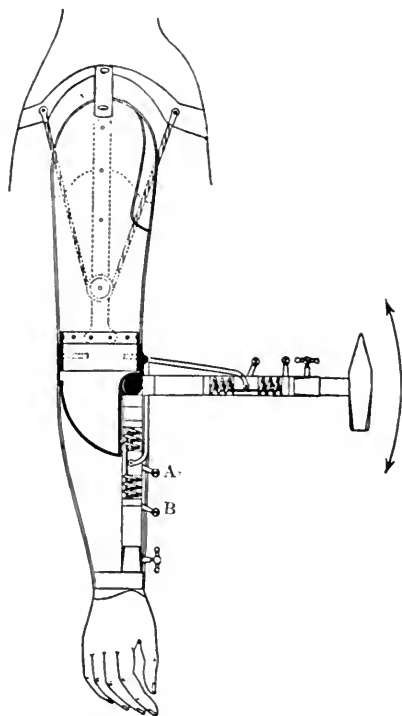
Fig. 154.—Artificial arm in which a limited amount of springy motion can take place at the elbow by adjusting the screws A and B. (*Model of Biesalski.*)

arm except by rotating the tool which is inserted into the hollow barrel corresponding to the forearm.

Two types of working arm have been constructed after the pattern of the ball-and-socket joint devised by the young carpenter's apprentice already mentioned. To render the fixation at the elbow firmer, a screw is attached to the elbow

articulation which locks the upper and lower arm against the spherical surface of the intervening steel ball (see Fig. 155). Although these two arms are capable of withstanding great strain, they are not, so far as I have been able to judge, as advantageous as that pictured in Fig. 152, because the tool is not brought into sufficiently intimate contact with the stump.
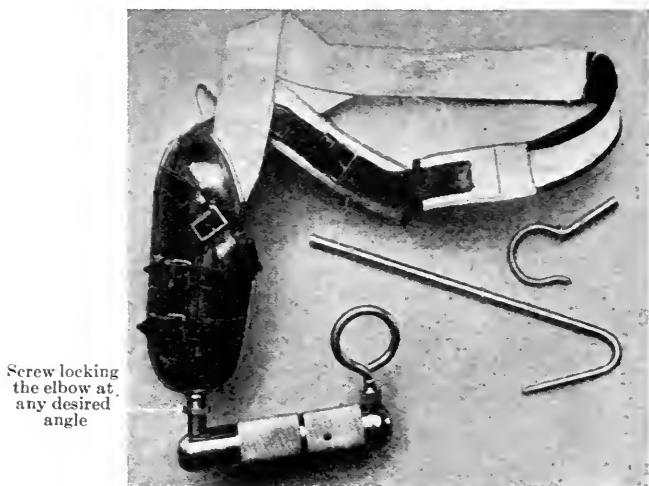
Screw locking the elbow at any desired angle

FIG. 155.—A working arm designed for amputations above the elbow (Rota arm). The joint at the elbow is so constructed that not only flexion and extension but pro- and supination are made possible. The portion corresponding to the lower arm consists of a tube into which tools of various kinds can be inserted. It can be fixed in any desired position by a turn of the screw just above the elbow joint.

As a rule, with practically no exceptions, the nearer the stump can be brought to the instrument which it is to control, the more effective is the amputated's use of the implement.

The Carnes arm already described in speaking of amputations of the forearm, is also applicable to amputations of the upper arm. The motor power is then derived by the movements of the shoulders (see Figs. 156, 157 and 158). The difficulty in learning to use the arm is increased when the amputation lies above the elbow, nor is it particularly well

suited to the use of the artisan. For æsthetic purposes, how-
ever, it is the most ingenious device of which I know.

The shorter the upper arm stump, the more difficult the
attachment of the prosthesis, and the more difficult it is to

Fig. 156.—A case of double amputation, on the right side through the
elbow, on the left 4 inches below the shoulder. In a case of this kind, unlike
that pictured in Fig. 171, an artificial limb is necessary, since the two stumps
cannot be approximated. The Carnes artificial arms are seen lying on the
table. The patient can put these on without assistance and is then able to
eat alone, dress, shave and use many tools. (See also Fig. 157.)

render the stump capable of doing its fair share of work.
As a rule it is almost impossible to train a patient with a
stump less than 4 inches long to be an independent farmer
or artisan. An exception is pictured in Fig. 163. Despite

the short stump, this young boy was able to work skillfully in the machine shop (see Figs. 159 *et seq.*). The prosthesis shows the excellent shoulder device designed by Riedinger. As a rule the patient with the short upper arm stump can be made capable of doing lighter garden work (see Figs. 164 *et seq.*), or in suitable instances, he can be trained to work at a

Fig. 157.—The Carnes artificial arm for the patient shown in Fig. 156.

factory machine. For this latter purpose close coöperation is necessary between physician, machinist, and the manager of the factory.

Even when the entire arm has been disarticulated at the shoulder, a prosthesis can be applied with distinct benefit to the wearer. The artificial limb is controlled by the swing of the body, and enables the amputated to wield a broom, rake, etc. In these cases as well as in the higher amputations

of the upper arm, the simple device shown in Fig. 164 has proven most serviceable. It consists of a round piece of wood resembling a spool, with a strap passing over it fixed on the one side, ending in a catch on the other side, similar to that frequently used on ice or roller skates. The handle of the implement, spade, rake, wheelbarrow, etc., is fastened between the strap and the spool. There is sufficient fixation for all purposes, and at the same time enough latitude of motion to allow the wheelbarrow to be tipped, or the angle of the rake to be changed.

The Life of the Amputated.—Care of the stump and the application of the artificial limb constitute only two of the numerous problems which confront the physician in the care of the amputated. Particularly in the case of those who have lost a hand, the entire mode of life must be modified. Nothing can be done as it was previously done, and the simplest actions of everyday life must be relearned. First, the amputated must be taught to dress and undress with one hand. The question of washing gave me considerable trouble, since the amputated were unable properly to cleanse the fingers and hand of the sound arm. The simple device pictured in Fig. 167, a board fitting over the wash basin, to which scrubbing brush and nail file could be attached, solved the problem. Lacing the shoes was another difficulty. Here I was aided by one of the amputated boys of the crippled children's hospital with which I was associated. He used a single, long lace, on the same principle as that employed in lacing a whip-stock. One end was firmly attached to the lowermost eyelet of the shoe. The other end was then passed through the eyelets in the usual way, and then, allowing a loop long enough to be zigzagged between the hooks, was passed beneath the lacings back to the starting point. The loop was then caught zigzag from one hook to another, and the slack taken in by a vigorous pull on the end of the lacing projecting beyond the first eyelet.

In eating, the only difficulty was occasioned by the need of cutting and using the fork with the same hand. For this purpose a number of devices are on the market. These consist of a knife-blade terminating in a fork-like projection
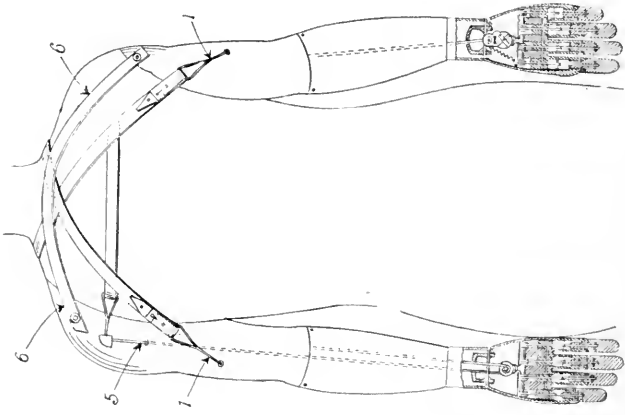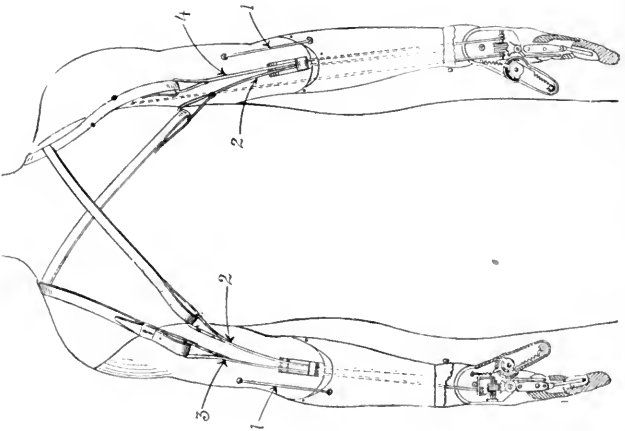
Fig. 158.

Fig. 158.—Two diagrams illustrating the principle of the Carnes arm for a double amputation, with one arm amputated between the elbow and the shoulder, and the other arm disarticulated at the shoulder. I. View from in front. II. View behind. The functions of the different straps are as follows:

Strap No. 1. Bends or operates the elbow. This strap coming from the back, passing over pulleys in the upper arm, and being anchored to the fore-arm, enables the wearer to get the elbow movement, simply by moving his stump forward a little.

Strap No. 2. Locks the rotating wrist. To unlock the wrist, the elbow is bent up to the extreme. When the wrist is not locked, it turns or rotates as the elbow is bent, but can be locked in any position desired, by first bending the elbow until the wrist and hand are rotated to the position desired, then hold it in this position while pulling on Strap No. 2, to lock it there.

Strap No. 3. Opens and closes the fingers. On the amputation above the elbow, by throwing the shoulder down, a sufficient tension is had on this strap to open or close the fingers; then, by raising the shoulder, the cord is pulled back into the hand, allowing the mechanism to reverse, and then, by again pushing the shoulder down, the opposite movement of opening and closing the hand is obtained.

Straps Nos. 4 and 5. Opens and closes the hand on the shoulder or dis-articulated amputation.

Strap No. 6. Simply an elastic support to hold the arm in place. For a single amputation on either side, the harness will be as shown, excepting that on the opposite side, it would simply be looped up under the good arm.

Straps No. 2 are the only ones which come across the chest and these are not tight, it being necessary to throw the arm out to the side, in order to lock the wrist.

For the diagrams and explanatory text I am indebted to the Carnes Arti-ficial Limb Co., Kansas City, Mo.

(see Fig. 168). The blade is convex, so that the food is easily cut by a rocking movement.

When the right hand has been lost, the patient must at once be taught to write with the left. This can be learned by the average man in about 3 weeks. It is advantageous to stimulate the patients by the competition afforded by class-room work.

Fig. 159.—Patient of Riedinger with very short upper arm stump.

In hundreds of ways, the physician can help the amputated to readjust themselves to the new mode of life; and in many instances the amputated will teach the physician and his comrades new methods of usefulness.

This training in proficiency, combined with the wholesome cheeriness of physician and instructor, does more than anything else to overcome the depression under which most of the patients are laboring, and fits them for the next important step in rendering them useful citizens of their community—specialized training of the stump, for the particular purposes for which it is to be used. For this of course the men must be divided into groups depending upon the type of amputa-

Fig. 160.—The same patient as in Fig. 159, equipped with a Riedinger prosthesis. Note the broad circular pad which closely surrounds the shoulder and serves as support for the leather socket which is attached to it by a strong joint, permitting motion in all directions.

Fig. 161.—The mechanic's tools employed by the patient shown in Fig. 160. These are inserted into the slot at the lower end of the forearm piece and fastened firmly in place by a turn of the screw.

Fig. 162.—The same patient as in Fig. 160, illustrating the method of using hammer and chisel.

Fig. 163.—The same patient as in Fig. 160 at work at the turning-lathe.

tion and the nature of the work.   In helping the patient to
decide what work he is fitted for, the physician should have as
consultant a staff of technical assistants versed in the details
of all the handicrafts.   Experience has shown that amputations
of the forearm and of the upper arm if not more than 2
or 3 inches above the elbow, do not debar a man from
becoming a carpenter, farmer, or some type of mechanician.

FIG. 164.—This patient suffered an amputation of the right arm $2\frac{1}{2}$ inches
below the shoulder.   Equipped with the Biesalski artificial arm shown in
Fig. 153 he was able to do all forms of light gardening.   Note the simple
contrivance at the wrist consisting of a spool over which a strap passes.   This
device gives a firm grip and at the same time allows sufficient play to dump
the wheel barrow.

Of course, those possessing an elbow-joint have a great ad-
vantage over those amputated above the elbow.   When the
amputation has occurred near the shoulder-joint, it is foolish
to attempt training a man for these branches.   He should then
be taught some handicraft allied to his previous occupation.
Thus, the carpenter should be taught sufficient mechanical
drawing and building construction to enable him to act as

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FIG. 165.—The same patient as in Fig. 164.   He is shown at work with the spade.

FIG. 166.—The same patient as in Fig. 165.   The spool device at the wrist enables him to use the rake effectively.

foreman; or, if he is not sufficiently well educated to assume this responsibility, he can be taught to be a furniture polisher. In this occupation, practically all the work is done with a sweeping motion of one arm; the other hand is used simply to hold the varnish or other polishing substance—a function which is quite as well filled by a small tray placed near the worker.

Fig. 167.—A simple toilet arrangement for the one-arm soldier. To permit proper cleansing of the hand, a scrubbing brush and a nail file are fastened firmly to the board which rests on the basin.

The artificial limb can be used to advantage in many instances, but for many men the stump is the best form of prosthesis. This applies particularly to a moderately long forearm stump. This can be used for filing, almost as effectively as the normal hand (See Fig. 169); for hammering, the
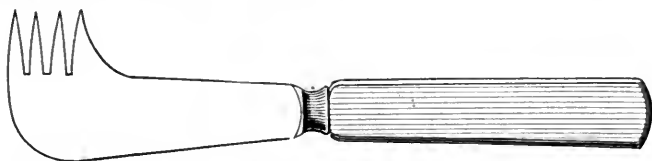
Fig. 168.—A combination of knife and fork for the one-armed.

handle is gripped in the elbow between the upper arm and the stump, as shown in Fig. 170. At the turning lathe, the stump can easily be trained to turn the adjusting swivel. In learning to use the stump, it is of great assistance to have an amputated man himself act as instructor. It is remarkable to what extent the delicacy of the skin improves. In one instance, in which I tested the fineness of perception by the two-point

test, used by the physiologists in determining the number of tactile corpuscles in the cutis, I found almost the same degree of sensitiveness of the forearm stump as that normally found over the finger tips.

Those suffering amputation of a lower limb do not require the same specialized training. All they need is the proper

FIG. 169.—The bracemaker's apprentice pictured in Fig. 170. Here he is shown in the act of filing. The stump had become so hardened that he was able to use it exactly as the ordinary mechanic uses his left hand.

stump treatment and the application of a well-fitting prosthesis to render them fit to return to their community. With rare exceptions, they are able to return to their previous occupations. The exceptions are the cases of double amputation or amputation near the hip in cases of men who previously

did hard manual labor. They must be taught a trade which allows them to be seated most of the time.

Far and away the most difficult problem presented in the care of the amputated is that of those who have lost both hands. Provided the stumps are sufficiently long to allow

Fig. 170.—The one-armed bracemaker's apprentice already pictured in Fig. 169. This illustration shows his method of gripping the hammer between the stump, upper arm and chest.

them to be approximated, the loss is not as tragic as it at first appears. In Fig. 171 is shown one of the teachers of the crippled children's home already referred to. He is seen in the act of buttoning his collar by means of a button hook held between the two stumps. This man had learned to dress

himself alone, to eat with delicacy and grace, to write a perfect hand with more than the normal speed, and had passed the examinations qualifying him as a licensed teacher. He did all this without use of artificial limbs. I also had opportunity of meeting several other men with double amputations who used their stumps as skillfully as he.

FIG. 171.—A teacher, both of whose hands had been amputated when six years old. He had learned to be absolutely independent and had passed his examination entitling him to a teacher's license. Without artificial limb he could dress himself (the illustration shows him in the act of buttoning his collar), shave, eat with grace and assurance, write an unusually legible hand with more than normal rapidity, travel long distances alone, carry a suit case and pay his fares, just as the normal individual would. All this was done by careful education of the stump, which in his case had acquired almost the same sensitiveness as the tips of the fingers.

When, however, the stumps are so short that they cannot be brought together, then an artificial limb must be applied—either the Carnes' arm (see Fig. 157), or Judge Corley's, since with sufficient training it enables the wearer to become a reasonably independent being, whereas without it he is absolutely helpless.

· The double-amputated require a school all to themselves, especially devised clothing with snap-hooks instead of buttons, trousers so devised as to fit directly to a vest (see Fig. 172), etc. In no instance, however, should the individual be allowed to

Fig. 172.—A patient with double amputation showing the vest and trowsers designed by Spitzy and a type of artificial arm attachable directly to the clothing. Note the ring hanging down from the slit of the trowsers. By pulling this upward with the hook of the artificial arm, the trowsers are closed by means of a thin chain with interlocking teeth.

feel that his case is hopeless. Even in one pathetic instance in which in addition to the loss of both hands the patient had been blinded by the explosion, much was accomplished and he left the hospital ready to assume a post in the office of a large business establishment.

CHAPTER XI

THE AIMS AND ORGANIZATION OF THE ORTHOPEDIC RECONSTRUCTION HOSPITAL

The effective treatment of the orthopedic cases referred to the Base Hospital demands a type of institution which hitherto has not existed. Its nearest analogue is the combination of Hospital and Home for crippled children, in which medical care is combined with vocational training. These institutions suggested the possibility of a similar type for the injured soldier. The necessity for a modification of the ordinary hospital is appreciated by all who, in reading the preceding chapters, have realized over how many months treatment must extend and how intimately the medical treatment is associated with the economic and sociological factors in the rejuvenation of the crippled soldier. The hospital should, in accordance with these varied aims, be divided into three main departments—the medical, vocational and administrative—and a fourth to act as a kind of clearing house in which the proper correlation of the activities of the other departments can be secured.

The medical department has three subdivisions:

(a) *The operating,* in which not only the open operations but also the bloodless procedures, such as corrective plasters, etc., are performed.

(b) *The department of physiotherapy.* This includes not merely the usual massage, hydrotherapy, electrotherapy and thermotherapy, but also the gradual correction of deformities by means of the methods outlined on page 92 *et seq.* An important adjunct of physiotherapy is, what might be termed, "workshop therapy." In outlining the treatment of joint injuries I emphasized the advantages of the workshop over the usual forms of mobilizing apparatus such as the pendulum devices, Zander machines, etc. These contrivances are ex-

ceedingly irksome both to patient and physician, and all too frequently defeat their own ends. The exercise which a patient gets in the workshop is on the contrary interesting and productive. If done under the proper guidance, the worker soon becomes enthusiastic and forgets the unpleasant symptoms in his desire to complete the allotted task. The physician must, of course, coöperate in every detail with the technician in charge of the shop. Thus for instance, he should suggest in the case of a patient, whose power of pronation and supination has been impaired, that such work as driving in screws, etc., should be tried; that for a patient whose right shoulder joint has been stiffened by adhesions, the opportunity should be given to saw and hammer. For injuries to the fingers, the finger work of the bookbindery and of classes in clay modeling are better suited. The latter, to my great surprise proved unusually popular among the soldiers under my charge, and much real artistic talent was brought to light in men, whose daily occupations gave no suggestion of their latent artistic capabilities. Practically for every type of injury an appropriate exercise can be found.

(c) The third subdivision of the medical department is devoted to the *manufacture of artificial limbs and braces.*

This work should, as I have tried to show in discussing the treatment of the amputated, not be left to the bracemaker alone, but should in all instances be under the supervision of the physician. Technical though the bracemaker's art is, it is, I think, far easier for the medical man to master its essentials than for the bracemaker to learn enough of anatomy, physiology, and pathology to ply his art with good result for the patient. Having the bracemaker's shop in the Hospital obviates the necessity of sending the patients away for fittings, and enables the physician to begin the manufacture of the splint while the patient is still in bed.

In constructing the braces much can be learned by consultation with engineers and other technical experts. In many respects bracemaking has lagged behind the age, and many tricks of the trade have been handed down from master to apprentice for hundreds of years without essential modifications. Of course, some of these are invaluable, whereas others,

when critically examined in the light of recent technical improvements, should be discarded. In another respect the bracemaking department is of unusual value. Even in times of peace the number of bracemakers scarcely suffices for the needs of the crippled. In times of war, when the number of amputated multiplies with enormous rapidity, it is absolutely impossible to find sufficient men versed in this branch to equip the crippled with suitable contrivances. By making the bracemakers' shop a division of the Hospital, the patients themselves can be taught to make their own splints; the mechanics are taught the metal work, the saddlers and cobblers, the leather technic.

For the amputated, particularly those living at a distance from the larger cities, it is absolutely necessary to be able to repair their own prosthesis. As already stated on page 199 . it is customary in one of the largest European Reconstruction Hospitals to insist upon a 4 weeks' course in the bracemaker's shop for every amputated soldier and he earns his discharge only after he has satisfactorily demonstrated his ability to construct his own artificial limb.

In addition to these three main subdivisions of the Medical Department there are, as in every Hospital, specialists for the various incidental diseases likely to occur when any large body of men are grouped together.

The Laboratory should be supplemented by a research department, since the treatment of gunshot wounds has so many unique phases that only by careful experimental work can the surgeon hope to solve the many problems which present themselves.

The second main department of the hospital, the vocational, is intimately associated with the first, since the various courses, not only in the arts and crafts, but even in clerical work, such as typewriting, serve as medical therapy. It may be divided into five subdivisions:

(a) *The Workshops.*—These should be as numerous and as varied in type as possible, so that irrespective of the nature of the injury or of the previous occupation of the patient, something can be found for which he is fitted.

The following are particularly useful:

Carpentering	Tailoring
Cobblering	Glazing
Smithy	Printing
Tinsmithy	Weaving
Plumbing	Fine mechanics
Painting	Watchmaking
Bookbinding	Bracemaking

Fig. 173.—The carpenter shop. Work of this type is invaluable not only as a form of physiotherapy for patients suffering from injuries to the shoulder, elbow and hand, but also as psychotherapy. The patient at the extreme left for instance, was suffering from marked neurasthenic symptoms due to the exertion and psychical strain of the war. His condition improved remarkably within a short time after he was allowed to begin carpenter work.

The detailed work in the shops requires the constant supervision of the physician, so as to bring about the most advantageous results. The impossible must, of course, not be expected. Thus for instance, if a man has a severe injury to the hand which prevents his gripping with the normal strength, then the instruments should be so modified as to enable him to grasp them despite the defect

FIG. 174.—The beginners' course in bookbinding for patients with injuries to the hands and fingers. Work in this shop constituted a routine part of the after-treatment of the tendon operations described on page 172 *et seq.*

FIG. 175.—A class in weaving for soldiers who have suffered injuries to the hands or fingers. The patient at the extreme left did excellent work despite a paralysis of the median and ulnar nerves, and the circulation in the hand improved distinctly through this type of exercise.

under which he is laboring. Fig. 177 shows a variety of modifications of the handles of planes and chisels for patients unable to flex their fingers completely. The increased circumference of the handle of the implement makes it possible to get a firm grip despite the injury to the flexor tendons.
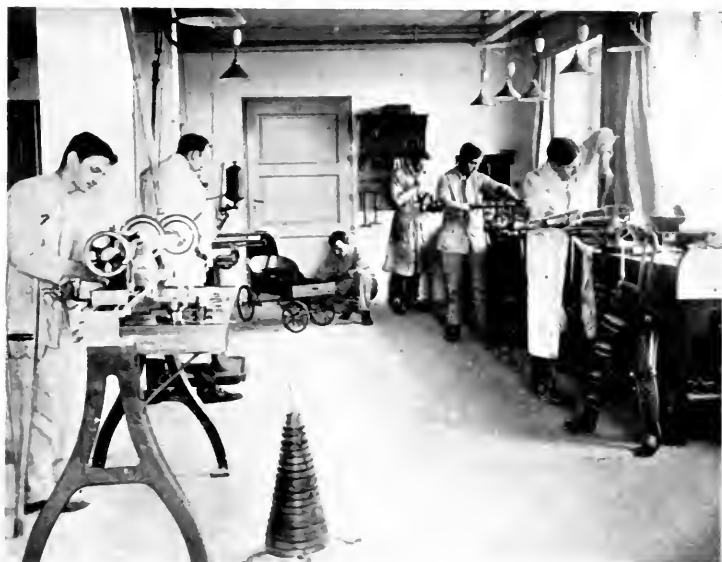
Fig. 176.—The Bracemakers shop. This serves a triple purpose: (1) It enables the Hospital to manufacture its own splints. (2) It affords opportunity for the crippled to learn a productive trade. The patient in the right foreground is working despite amputation of the right hand. (See also Figs. 169 and 170.) Back of him stands a lad whose right arm is crippled by a marked deformity of the ulna. The patient in the left foreground is manufacturing his own artificial limb for a disarticulation at the hip. (3) It acts as a form of physiotherapy and enables all the amputated to learn how to repair their own artificial limbs.

In Figs. 178 *et seq.* are illustrated similar means of helping another type of injury. The badly mutilated hand is that of a butcher, who because of the missing fingers found it impossible to continue at his trade. The difficulty was easily solved by taking a clay impression of the patient's fist, and modeling the handles of his knives correspondingly.
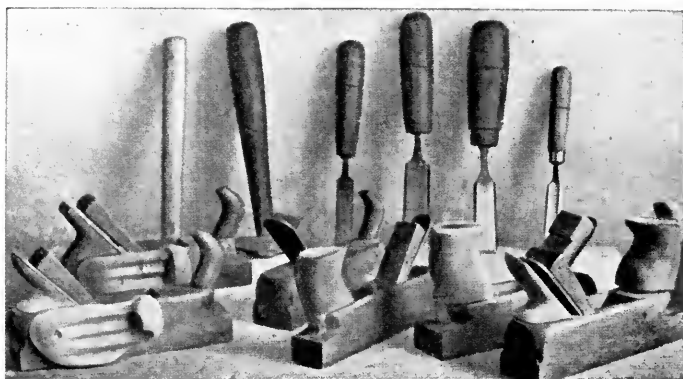
Fig. 177.—Carpenter's tools for soldiers with crippled hands. Note the enlarged handles enabling the patient to grasp the tool, even though the flexor tendons are not able to function normally.

Fig. 178.—Badly mutilated hands of a patient, who in civil life had been a butcher. To enable him to grasp his knives, a clay impression of the grip of his right hand was taken and the handles of the knives correspondingly carved. See Figs. 179 and 180.

In the shoemaker's shop the device shown in Fig. 181 was a great assistance to the amputated and to those who were unable to bend the knee or the hip.   For the patients with an ankylosed hip, a special chair, Fig. 182, so made as to support the sound leg without interfering with the injured, proved helpful.

FIG. 179.—Butchers' knives, carved so as to permit their effective handling by the patient depicted in Fig. 178.

If the patient has suffered amputation of both legs or a high amputation of one, then an occupation should be selected which enables him to work when seated; thus for instance a man with a mechanical turn is taught the fine mechanics, necessary for instrument making, construction of microscopes, watches, etc.   A smith is taught how to do fine hammered iron or brass work.   In other words the man's previous training and his natural bent are in every instance taken into consideration.

Fig. 180.—The same patient shown in Fig. 178, illustrating how, despite the absence of three fingers, he was able to get a firm grip of his knife.

Fig. 181.   Fig. 182.

Fig. 181.—Apparatus to replace the knee strap used by the cobbler.   This simple device enables the shoemaker who has lost a leg to work without inconvenience.

Fig. 182.—A chair designed for patients suffering from an anchylosis of the left hip.   (Biesalski model.)

(b) *The agricultural subdivision*, including dairying, is of particular importance, since here the hospital affords an unusual opportunity to increase the productive power of its inmates.   The leader of this department should be thoroughly trained in the most modern methods of farming and should, of course, be of a sufficiently practical turn of mind to render his knowledge digestible for his pupils.
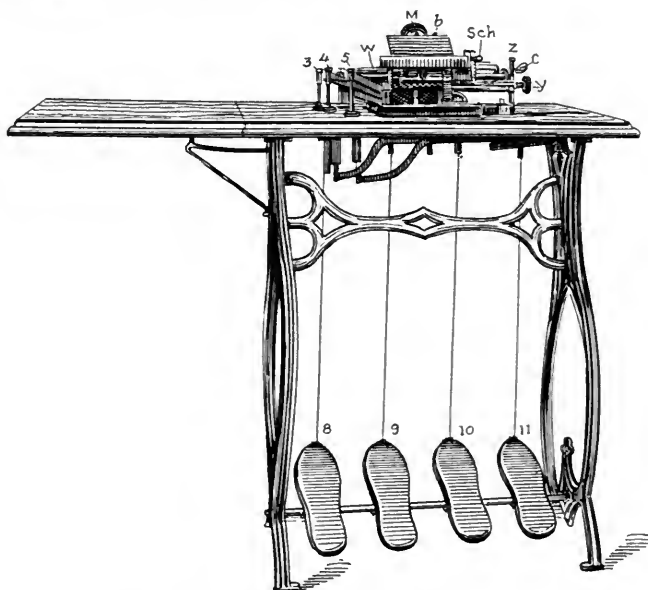
Fig. 183.—A modified typewriter for the one-armed.   The pedals are connected with the spacer and shift key.

Loss of a leg below the knee or shortly above does not incapacitate, nor does the loss of one hand, when the amputation has occurred below the elbow.   Loss of the entire lower arm is a much more serious affair, but even under these conditions I have known of several men who have been able to continue as farmers, when equipped with a suitable artificial limb.

The business school with courses in bookkeeping, stenography, etc., is helpful not only to the artisan who is to become

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a bookkeeper, but to the businessmen, salesmen, etc., who in this way increase their technical knowledge of business methods. Typewriting is a most effective form of mechanotherapy in certain injuries to the wrist and to the fingers. For the amputated, and for the patient whose hands have been severely crippled special devices are necessary. Fig. 183 shows a simple modification of the typewriter, in which the spacer and some of the other switches are attached to a pedal. In case this device cannot be had, it is easy to improvise a strap attached to the spacer running beneath the patient's thigh. When fingers have been lost or cannot flex normally, pen and pencil can be modified on the same principle as the carpenter's tools shown in Fig. 177. Each patient should be regarded as a specific problem and no matter how great the pressure of medical duties, the physician must have time to consider the individual needs of each man.

For other patients, unsuited to the workshop or to the business school, who, because of the tedious convalescence, find that time hangs heavily on their hands, *general culture courses* are indicated. This part of the vocational department should be under the supervision of a well-trained teacher able to secure the coöperation of specialists in those subjects of interest to the patients.

One feature frequently omitted in reconstruction hospitals is *the athletic department.* It is almost as important for the purpose of physiotherapy as the workshop or the school room. Fig. 184 shows a game of hand ball in which all participants had suffered amputation of either leg or arm. Vigorous competitive athletics not only drive away the blues, but act as a beneficial form of mechanotherapy. I distinctly remember one patient whose shoulder had been stiffened by an ugly gunshot wound. I advised him to join his comrades playing ball. Within a week the shoulder was practically normal. Of course, vigorous athletics cannot be recommended for every patient, and in each instance a sufficient length of time must elapse after the wounds have healed before it is advisable. As in every other department of the hospital, careful medical supervision is necessary.

The third main division of the hospital, the administrative department, must assume not merely the functions usually assigned it in the ordinary hospital, but must include in addition to its staff of bookkeepers, stewards, etc., two other subdivisions.

The first has to do with military matters. A reconstruction hospital controlling several hundreds of men whose general health is excellent must be run with military discipline, other-

Fig. 184.—A game of volley ball, in which all the contestants had suffered amputation, either of leg or of arm. The men played with vim and lost all consciousness of self in the sport.

wise the patients tend, in their exuberance, to become unmanageable. However sympathetic and kindly disposed the hospital authorities are, they must constantly bear in mind that the patients are still soldiers and that rigid discipline must be maintained. Rules regarding furlough, taps, etc., must be strictly obeyed as in a military camp and, if necessary, offenses must be punished. In addition to maintaining discipline, the military department has to do with the awarding of pensions, payment of salaries, and discharge from the army.

Of even more importance is the *second subdivision, the employment bureau.* It is manifestly unfair to discharge a

crippled soldier who has lost the use of a limb in the service of his country and allow him to shift for himself.   The state is responsible not merely for the proper medical supervision, supplying a brace and giving the patient the necessary technical education, but it must also provide the crippled soldier with an opportunity to earn his livelihood.   The employer, as a rule, looks askance at a cripple who applies for a job. The employment bureau must educate the public to the necessity of giving the crippled man a fair chance, and the pension must be so awarded that the discrepancy in salary between the cripple and the normal worker is balanced.   In some of the belligerent countries the employers rapidly responded to the call and formed associations to assist the employment bureau in placing the crippled in advantageous positions.   Economic necessity, too, will help educate the employer, for with the growing scarcity of labor, every individual, whether crippled or not, is bound to be sought after.   The task will be made easier by the state or local public employment agencies, some of which have already done work in this field.

The fourth and final department of the Hospital is necessary to correlate the three other divisions.   It follows the hospital career of each inmate from the time of his admission until his discharge and sees to it that there is no duplication of effort or unnecessary delay.   Its staff should consist of the heads of the other departments or their representatives and of a sufficient number of trained clerks.   The patient is brought to this department as soon as he is admitted to the hospital.   It decides upon the general course of treatment and refers the patient to the appropriate ward.   Thus, for instance, assume that a number of wounded soldiers are admitted to the hospital.   The first is amputated.   He is examined by the medical officer in charge of amputations who decides whether the stump is suited to the application of an artificial limb, or whether operative measures or correction of contractures by means of splints are necessary.   If these are not indicated, the patient is referred to the head of the brace-makers department who at once takes necessary measurements and determines the date for the delivery of the artificial limb.   The clerks meanwhile have taken the personal record

of the patient and properly filled out the folder in which the various papers—medical, military, social—relating to the patient can be filed away.

Another patient of the group has an injury to one of the peripheral nerves.   He is examined by the physicians in charge of the neurologial ward who decides whether the case is one for nerve or tendon operation, or, in case the patient has already been operated upon elsewhere, what type of splint is necessary and what form of physiotherapy.   It may be that no further medical treatment is indicated.   In that event the head of the vocational department is called upon for advice. He confers with the physician as to the nature of the work which the patient is best fitted to perform.

A third patient has a non-union of the femur.   The surgeon in charge of the ward dealing with injuries to bones decides whether operation should be performed at once, or whether conservative treatment should be tried.   If a splint is necessary he is taken in charge by the head of the brace department and placed in the suitable ward.   Since healing will require several months, he is also referred to the vocational department for educational work during his stay in the hospital.

The fourth patient has a contracture of a joint.   He, too, is examined by the ward physician in charge of joint injuries and contractures, and referred either to the operative division or to the physiotherapeutic department.

These four cases represent the four main types of injuries referred to the hospital, and in outlining what happens to them an idea is given of the routine procedure of this centralizing bureau.

As the patients progress from one ward to another, from the operative to the physiotherapeutic, and from this into purely vocational wards, their course is followed by the clerks who register the notes sent them by the respective departmental heads, relative to time of operation, delivery of splint, enrollment in workshops or business school, etc.   If there is a hitch anywhere it can be noted at once, and called to the attention of the physician in charge.

Construction of the Hospital.—The unit system is the best, since it allows readily for expansion and adopts itself excellently

to the systematization outlined in the preceding paragraphs. The patients are referred to the barracks according to the type of injury and the nature of the treatment; thus, there is the ward for the amputated, whose stumps still require surgical intervention, another for those whose prostheses are in course of construction, etc. The barracks are arranged somewhat in the style of a military camp, with, of course, due regard to the medical exigencies. The operating pavilion should be connected by a covered, well-warmed passage with the ward for the immediate reception of postoperative cases. If this precaution is not adopted there will be an unduly high percentage of postoperative pneumonias. In planning the internal arrangement of the pavilions, opportunity should be given for initiative on the part of the physician in charge.

In selecting the personnel for the hospital, special care must be taken in the selection of the chief orthopedic surgeon, for with him rests success or failure. He must be a master of his art, thoroughly versed in reconstructive surgery, in orthopedic after-treatment, and in the application of braces. Besides, he must have a social conscience and a ready sympathy for the individual needs of his patients.

The other members of the hospital staff must also be chosen with care, and particular reference must be paid to grouping together men who are in sympathy with the common aim of the hospital, and who, despite the differences in their technical qualifications, are one in their ability to work harmoniously with their fellows.

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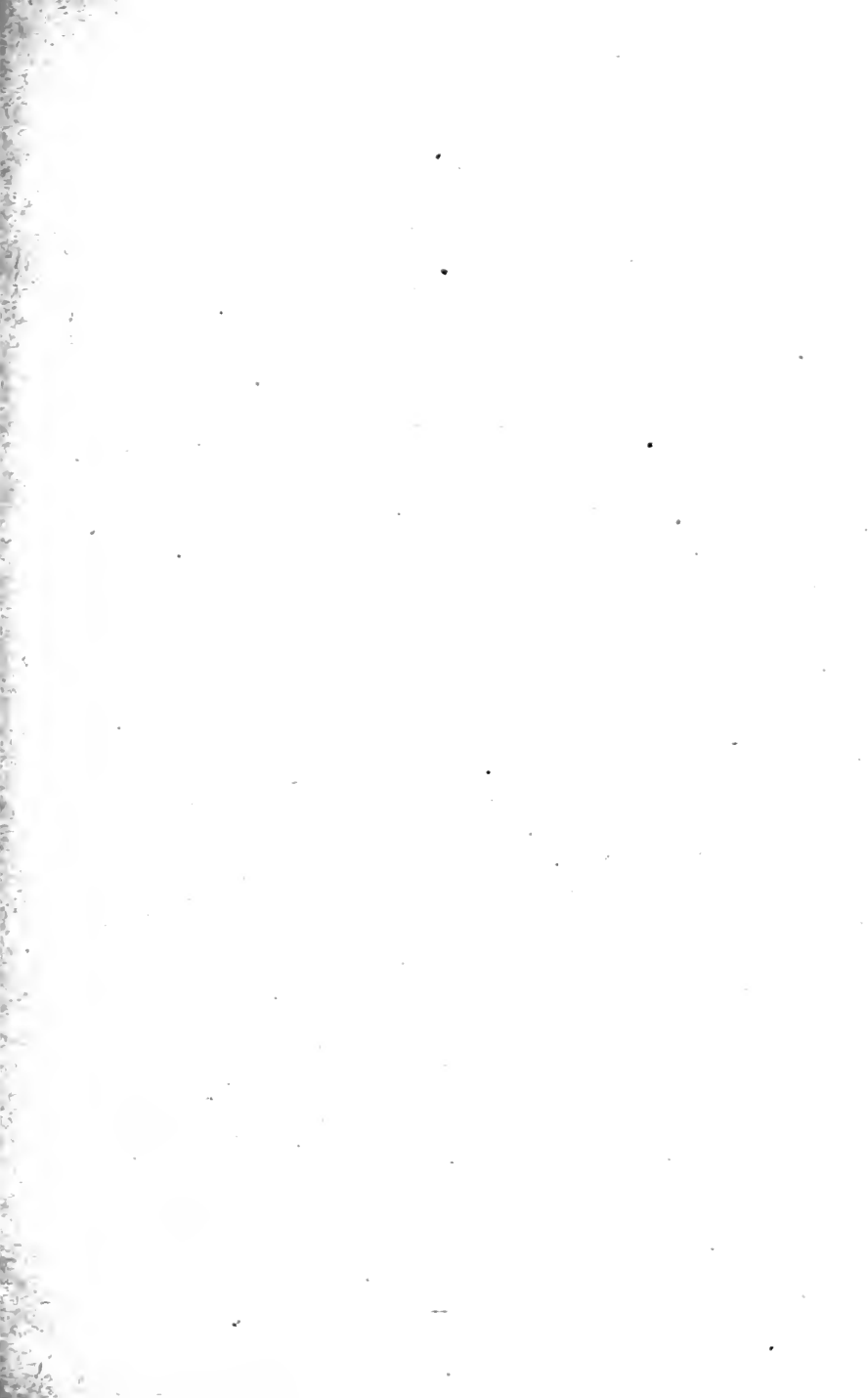
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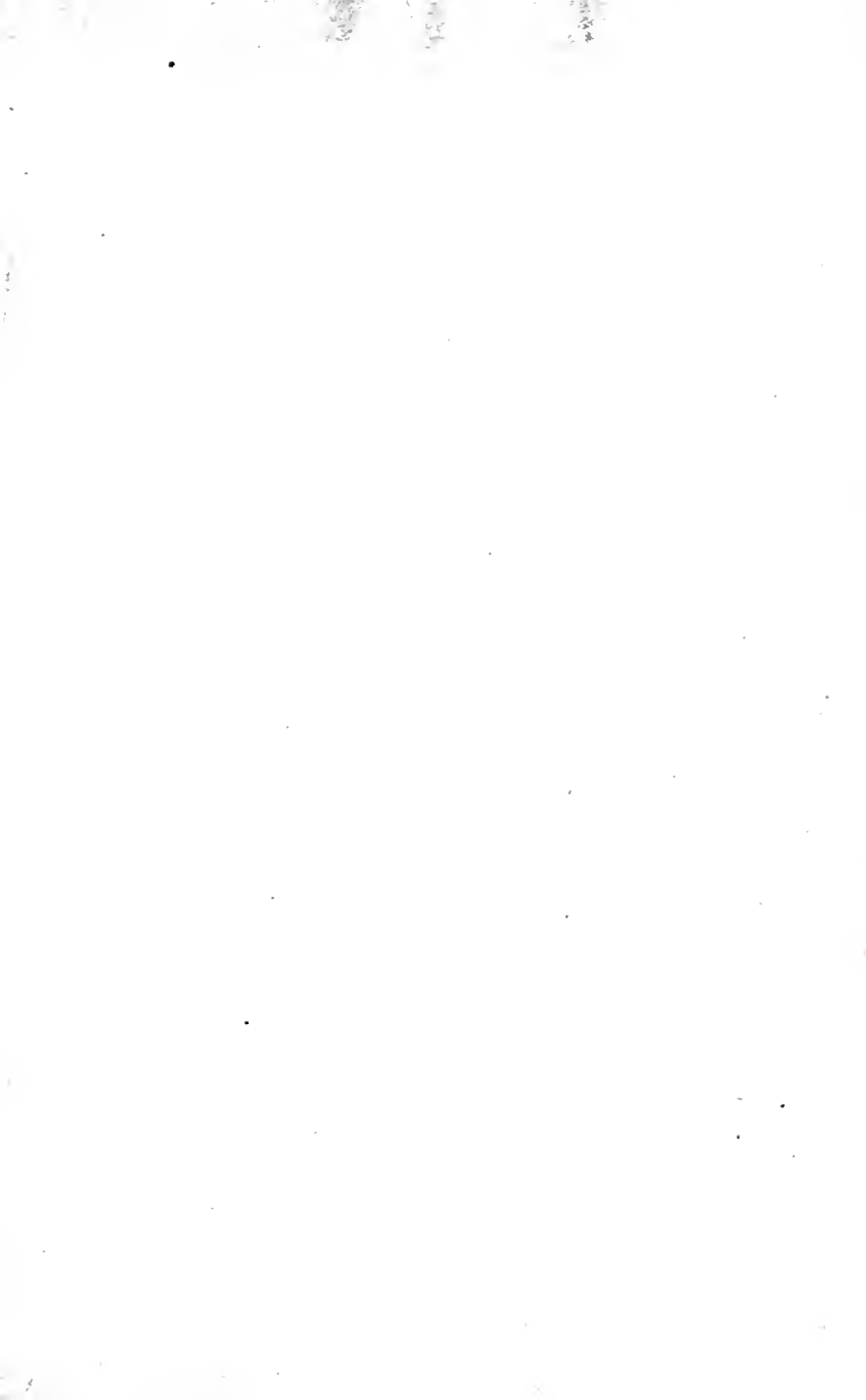
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